US Army Corps
of Engineers
Los Angeles District

COAST OF CALIFORNIA
STORM AND TIDAL WAVES STUDY

SHORELINE MOVEMENT INVESTIGATIONS REPORT PORTUGUESE POINT TO MEXICAN BORDER (1852-1982)

CCSTWS 87-10
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SHORELINE MOVEMENT INVESTIGATIONS REPORT, PORTUGUESE POINT TO THE MEXICAN BORDER (1852-1982)

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Coast of California Storm and Tidal Waves Study

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PREFACE

This report is the result of a cooperative effort of the National Ocean Service (NOS), National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and the Los Angeles District (LAD), U.S. Army Corps of Engineers. Data reduction and quality control were performed by NOS; data analyses and report preparation were done by Moffatt and Nichol, Engineers under contract to LAD (DACW09-86-D-0005).

The report was prepared by Dr. Craig H. Everts of Moffatt and Nichol, Engineers for the Coast of California Storm and Tidal Wave Study at LAD. At the time the report was prepared Mr. Thomas Dolan was project manager. The present project manager is Dr. A.L. Kadib. Mr. Dolan and Ms. Pamela Castens, the contract monitor, offered helpful review suggestions that significantly improved the report.

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INTRODUCTION

Shoreline maps were recently completed by the Natural Ocean Service (NOS) for the 132-mi long coastal reach between the US-Mexico border and Portuguese Point, California. The earliest survey in 1851 covered some, but by no means all of the study reach. The latest shoreline position, established in March 1982 using aerial photographs taken for that purpose, covers the whole study reach. In some areas eight surveys were made between 1851 and 1982 while in one area the period of shoreline coverage is 1959-1982 in which only three surveys are available.

1. Objectives. The first objective of the investigation described in this report was to determine which of the NOS shorelines could be used in coastal planning, engineering and research. Because the shorelines were surveyed many years apart, their usefulness is limited to establishing net shoreline changes and net shoreline change rates. The shoreline maps are further limited in application to coastal reaches where shoreline position changes exceed specified uncertainty limits. The second objective of the investigation was to interpret the trends in net shoreline behavior in those reaches where the uncertainty in a shoreline position change between two or more surveys was less than the measured change.

2. NOS Maps. The NOS maps represent the longest semi-quantifiable data set on shoreline changes available in southern California. The 130-year time span between some of the shorelines is two to three times the span covered by

usable aerial photographs. NOS map data thus allows a more extended temporal analysis of variations in shoreline change rates than available elsewhere.

In the absence of other data, past shoreline changes usually provide the best available basis for predicting future changes. An extrapolation of past changes is not without risk though. Man's actions have significantly affected the natural coastal processes and may thereby have altered the rates and patterns of shoreline change. Natural processes that affect the shoreline may also have changed over time.

A direct application of the interpretations given in this report is risky. The small number of surveyed shorelines available for analysis at any given location and the uncertainties in using the shorelines to establish net shoreline change rates limit their usefulness to semi-quantitative applications in the absence of other data. Accordingly, causes of shoreline behavior suggested in the report are somewhat speculative. They best serve as working hypotheses that should be tested by rigorous field investigations and more detailed office analyses.

This report is intended for use in conjunction with the special-purpose shoreline maps published in 1984 by the National Oceanic and Atmospheric Administration, National Ocean Service (NOS). The maps are available from the U.S. Army Corps of Engineers, Los Angeles District, Coastal Resources Branch, P.O. Box 2711, Los Angeles, California 90053-2325. Twenty U.S. Geological Survey quadrangle maps (scale = 1:24,000) were used as a base for the fifteen shoreline change maps. Shoreline position data extracted from 127 shoreline surveys at scales of 1:5000 to 1:20,000 were the basic data set. Older surveys, made in 1851 to, but not including 1972, used planetable methods. In 1972 and 1982 the shorelines were established using photogrammetric methods.

A discussion of how the map shorelines were established is presented in a companion report that should be consulted when the maps are used:

> Shoreline Movement Data Report, Portuguese Point to Mexico Border (1852-1982), U.S. Army Corps of Engineers, Los Angeles District, Report CCSTWS 85-10, December 1985, 49 p.

For information concerning coastal processes in the reaches covered by the maps the following summary report should be consulted:

> Southern California Coastal Processes, Data Summary, U.S. Army Corps of Engineers, Los Angeles District, Report CCSTWS 86-1, February 1986, 572 p.

Information contained in these reports is not, for the most part, reproduced in this report.

3. Map Shorelines. The shoreline on the maps is defined by NOS as the mean high water (MHW) shoreline. It is the conceptual intersection of the still water surface of the ocean at MHW elevation with land. In certain cases shorelines obtained from aerial photographs and published Corps of Engineers survey data are included to supplement the map shoreline data.

A map shoreline is the shoreline that existed at the moment the shoreline survey was made. It may be at any position within its reversible range.

Reversible changes in shoreline position, i.e., shoreline movement one way then back again without a net change, occur on all scales of time. Storms in the autumn and winter typically cause sand to be moved offshore resulting in shoreline retreat. During post-storm periods, usually spring and summer when wave heights are lower and wave periods are longer, the sand typically moves onshore again and the shoreline advances seaward. It is not possible to establish where the map shoreline was in the reversible shoreline change cycle when the survey was made.

The actual net change in shoreline position between surveys is the relatively long-term change that occurred when reversible movements of the shoreline are removed. The calculated net change in shoreline position obtained from the maps is the shore-normal distance between two or more shorelines surveyed at different times. The actual net change thus is within the bounds of the map position of the shoreline plus or minus uncertainty in that value at the time of the second survey minus the map position of the shoreline at the time of the first survey plus or minus the uncertainty. The calculated rate of shoreline change between surveys is the calculated net change divided by time between surveys.

4. Conversion of Shoreline Position Change to Sediment Volume Change. It was sometimes useful to convert shoreline position change to sediment volume change in order to facilitate the interpretation effort. For example, when a known quantity of beachfill was added to the Newport Littoral Cell the shoreline advanced seaward. The profile seaward of the shoreline, or shoreface, also advanced and the magnitude of shoreface advance was dependent on the volume of added fill, the depth at the base of the shoreface, and the elevation of the beach berm. The depth of the base of the shoreface varies

from 15 to 45 ft below MHW depending on location along the southern California coast (Moffatt & Nichol, Engineers, 1987; Everts et al, 1987; and Everts, 1988). The berm elevation is usually 4 to 10 ft above MHW.

The vertical dimension of the shoreface, h_S, is the difference between the elevation of the berm and the depth at the base of the shoreface. When the average shape of the shoreface remains unchanged as the shoreface retreats or advances the net sediment volume change, ΔV, is related net shoreline change, ΔS, for the same time period as

$$\Delta V = \frac{\Delta S}{h_s \; l} \qquad (1)$$

in which l = longshore dimension of shoreline reach. The assumption of an unchanging shoreface shape is based upon the observation that the shoreface profile fluctuates about a dynamic equilibrium shape over a time period on the order of many years (Moffatt & Nichol, Engineers, 1987; Everts et al, 1987). Shoreface shape is primarily controlled by sediment size and the wave climate. The average wave climate changes relatively little over a long time period. Consequently, the shape of the shoreface usually changes relatively little if the composition of shoreface sediments is not severely altered.

5. Mile Designations and Coastal Compartments. Shoreline mile designations were established for ease in describing shoreline location. Latitude boundaries used by Everts et al (1983) on the U.S. Atlantic coast are not as easy to visualize in the study area as mile boundaries. Longshore distances between latitude boundaries varies greatly as the shoreline orientation changes between the US-Mexico border and Portuguese Point. Most importantly though, as the shoreline changes from a north-south trend, where latitude

boundaries can be used, to an east-west trend, a shift must be made to longitude boundaries. This complicates boundary designations to the extent that equi-distant mile boundaries become much more desireable.

Longshore boundaries were established, by mile, north of the US-Mexico border which is the origin. Except for major changes in shoreline orientation at Point Loma, Point La Jolla, Dana Point, and Point Fermin, the distance between mile boundaries was held constant at 5280 ft in straightline distance along the 1982 shoreline. Straightline distances were used because topographically rough reaches of the coast with many headlands greatly distort the mileage scale. At the four major headlands, two straight shoreline segments with orientation shifts about the point were used to establish the mile boundaries. Mile designations continue across river, lagoon and bay entrances.

The coast was segmented into major coastal compartments (Fig. 1). Each compartment is treated separately in this report. Beginning at the US-Mexico Border the compartments are:

1. Silver Strand Littoral Cell
2. Mission Bay Littoral Cell
3. Oceanside Littoral Cell
4. Laguna Beach Compartment
5. Newport Littoral Cell
6. South Palos Verdes Compartment

Three reaches are especially noteworthy because of the relatively large shoreline changes occurred there. These are the Silver Strand Littoral Cell (Mile 0 to Mile 13.6), the Oceanside Subreach (Mile 53 to Mile 63) in the

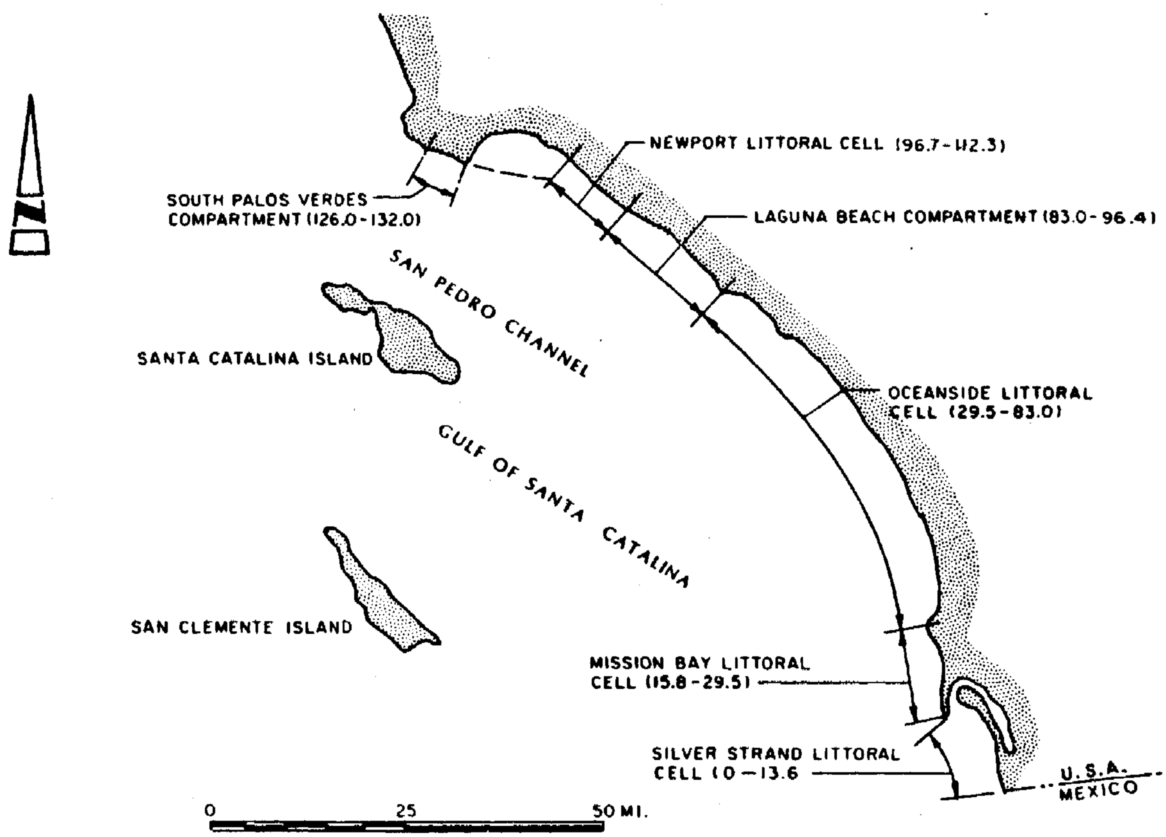

Figure 1. Location map showing coastal compartments between the US-Mexico border and Portuguese Point, California; miles north of US-Mexico border are given in parentheses.

Oceanside Littoral Cell, and the entire Newport Littoral Cell (Mile 96.7 to Mile 112.3). A subreach is a designated part of a littoral cell, usually with alongshore boundaries at a headland, river outlet or lagoon entrance. Subreaches were established to separate long littoral cells into workable segments for analysis and interpretative reasons. The north one-half of the San Pedro Littoral Cell (Mile 112.3to Mile 126) is not considered in the analysis is because it is in the lee of the Los Angeles-Long Beach Breakwater and its shoreline is predominantly controlled by structures.

II. EVALUATION OF MAP DATA

Shoreline change distances obtained by a comparison of two or more shorelines surveyed at different times are subject to uncertainty. Consequently a net shoreline change obtained from the maps should be considered to lie within a range of probable distances, rather than to be a single distance. Errors made during the data collection, data reduction and data analysis phases of map production are the human part of the uncertainty. Reversible movements of the shoreline, best represented by the natural seasonal fluctuations common in southern California are the second elment of uncertainy. They reduce accuracy when the net change in shoreline position is the desired parameter.

Uncertainties introduced by human and natural factors are considered first in this section. A maximum range of uncertainty is designated. Net shoreline position changes and net shoreline change rates obtained using the NOS maps are next compared to rates and positions obtained using aerial photographs and surveyed profile data. The results indicate the practical, useful range of uncertainty is about half the maximum range. When calculated shoreline changes from the NOS maps exceed the practical range, the data were found to accurately define the trend in shoreline behavior, and semi-quantitatively to define the actual rates of change.

1. Maximum Uncertainty.

(a) Human Error. Human factors that produce uncertainty include the use of incorrect selection criteria to define the MHW line, survey errors, errors introduced when raw field data are reduced, errors introduced when the shorelines on original manuscripts are converted to common-datum and common-scale shorelines on the NOS shoreline maps of 1984, and errors resulting from the shoreline comparison analyses using the maps. The maximum probable human-factor error, if all errors were cumulative, is about 120 ft as shown in Table 1. The actual error is less because all errors are not cumulative. Errors resulting from survey, recording and analysis procedures are mostly random.

TABLE 1. Uncertainties Involved in Comparing Two NOS Map Shorelines

TYPE OF UNCERTAINTY	UNCERTAINTY (feet)[1]
A. Resulting from Human Factors.	
1. Selection of MHW shoreline before 1972	20
Selection of MHW shoreline after 1972	20
2. Survey errors, plane tablemethod before 1972	30
Aerial photograph data extraction after 1972	40
3. Errors in reducing field data	20
4. Datum errors	10
5. Map copies and reduction errors	40
Total maximum cumulative uncertainty caused by human factors	120 ft
B. Resulting from Natural Factors.	
Total maximum uncertainty resulting from natural factors	120 ft

[1]see text for explanation of how uncertainty was derived

Two potential errors exist in the selection of the MHW shoreline in the field. First, the criteria used in selecting the MHW line may not actually produce that line. Second, the field selection itself may not be accurate.

The methodology used to select the MHW shoreline varied between surveys. Prior to 1972 it was established on the ground using a plane table. The shoreline in 1972 and 1982 was obtained from mapping-quality aerial photographs. The MHW shoreline, measured at the time the field survey was made, was marked with stakes for later reference purposes when hydrographic surveys were made. Leveling methods were not used to establish the MHW shoreline. Rather, its location was based on physical appearance. Most commonly the MHW shoreline was defined and established by the field surveyor at the debris line left from the previous high tide (Shalowitz, 1964). The driftline left by storm surges was disregarded (Wainright, 1898). Tidal elevation was considered and most surveyors were experienced observers.

It is relatively easy to identify and fix the location of the debris line. Therefore the field selection of that line should produce a small error, probably less than 5 ft. When quantities of floating debris are absent, however, as often is the case in southern California, small particles of debris in intermittent patches or lines must be used or the surveyor must resort to other selection criteria. Prior to the rapid human development of the southern California coast following the Second World War, most of the debris probably came from two natural sources: (1) rivers with seasonal input to the ocean, and (2) kelp, seagrass and other organisms from the ocean which become available when detached from the seabed or when torn loose from growing plants by storm waves. The quantity of this debris reaching the beaches from both sources varies seasonally. Quite likely the surveyors had to use selection criteria other than a debris line some of the time. Shalowitz (1964) notes differences in sand coarseness and compactness, and sand color differences, were also used to discriminate the MHW s oreline in the absence of a debris line. A more detailed discussion of MHW line selection criteria is given in Everts et al (1983).

It is not possible to quantify inaccuracies that result when a debris line is absent. Uncertainties involved in the assumption that the debris line is the MHW shoreline, however, are probably greater than inaccuracies in establishing the debris (or other) line in the field. The debris line forms considerably above the MHW line near the time high tide begins to recede. Its elevation is at the upper limit of wave uprush on the foreshore and well above the actual intercept of the still water line and the beach surface at the time of high tide. Since the MHW line was selected in the same way for all surveys prior to 1972, its relative elevation between those surveys will vary only as the debris line elevation varies between surveys.

Storm surges were not considered and the surveyors were well aware of the tide elevation at the time they made their survey. The lower of the two daily high water periods does not leave a lasting debris line. Only the daily high water debris line was considered. Based on a debris (or other) line criterion, the difference in elevation of the selected MHW shoreline was probably not greater than 1 ft from one survey to the next at the same beach. With an average 1:5 to 1:20 foreshore slope, the horizontal range in shoreline position between surveys resulting from different elevations of the debris line is about 5 to 20 ft. Twenty feet is considered the maximum combined uncertainty in shoreline position that results from an imperfect selection criterion, and from selection inaccuracies in establishing the MHW shoreline at the time the survey was made.

In 1972 and thereafter the location of the MHW shoreline was established using aerial photographs. Shoreline analyses using aerial photographs requires the interpreter consistently and objectively identify a line in the coastal zone. This line must either be the shoreline of interest, or it must be a line that changes position directly with, or in a known relationship to, the shoreline of interest. Possibilities include the vegetation line, dune line, water or swash line and wetted bound.

The wetted bound is usually the best shoreline position marker. It does not vary appreciably over a tidal cycle (Langfelder and Stafford, 1979; and Dolan and et al 1979), it is identifiable on most coastal aerial photographs, it is continuous along the shore, and it approximates the shoreline used by NOS. The wetted bound is the line forming the boundary between sand saturated at the time of high tide and drier sand landward of that limit. Dry sand is light gray on aerial photos. Dolan, et al (1979) found that the wetted bound moved an average of only 2 to 6 feet over a tidal cycle. The wetted bound position is dependent upon changing wave conditions, tidal elevation, and water table fluctuations which cause variations from an "average" location. Sometimes a debris line obscures this boundary on aerial photographs. Uncertainties in the MHW selection process are probably similar or slightly less than they were when plane table methods were used.

For the earlier plane-table surveys Shalowitz (1964) notes that with normal local control it was possible to measure distances with an accuracy of 3 ft and locate the plane table within 6 to 10 ft of its true position. He further notes errors in identifying the actual high water (not MHW) line may be 10 to 12 ft such that actual location of the high water line on early surveys is within a maximum error of 30 ft and possibly much more accurate than that. Shalowitz (1964) further notes errors of as much as an additional 30 ft could result from irregularities in the high water line not visible to the topographer. This error is probably of minimal consequence in the study area because shoreline irregularities would be averaged out in establishing the net shoreline retreat rate. Most sandy southern California beaches, even those contained between nearby headlands, are usually quite smooth in planform.

Errors in high water line location were not allowed to accumulate. Shalowitz (1964) notes the position of the line was constantly controlled by triangulation. Surveys were not synoptic. They generally took months, and in some cases years. So temporal changes in the shoreline, especially between far-removed reaches, were possibly great.

The MHW line usually can be located to within ±0.5 mm on the maps. At a map scale of 1:24,000 the uncertainty in position is ±39.5 ft. The uncertainty is ±16.5 ft. on an historic map with a scale of 1:10,000. The 0.5 mm map scale accuracy was maintained when source maps were reduced to 1:24,000. The ±39.5 feet accuracy bound is a maximum. Everts et al (1983) note a recent Florida shoreline mapping project checked the results obtained from an analysis of NOS manuscripts and aerial photographs using a field traverse and found a location error of ±10 feet. This suggests the accuracy will be significantly better than ±39.5 feet.

Errors involved in reducing field notes and in the subsequent production of the shoreline map (T-sheet) for a specific survey are unknown, but are likely less than 20 ft. They would not likely be cumulative in an alongshore direction or between surveys.

All post-1927 historical maps were compiled using the 1927 North American Datum. Adjustments were made when possible to uncorrected pre-1927 maps for the shoreline mapping project. When accuracy requirements could not be met the chart was not used (USACE-LAD, 1985). Datum errors in pre-1927 shoreline positions are consequently small (less than 10 ft) compared to other potential errors and uncertainties.

One hundred sixty-five historical maps were available and 127 were chosen. Incompatible map scale, distortions and datum problems accounted for the rejection of 38 maps. Bromide prints were made of original maps. These were subsequently transferred to matte-finish film positive to obtain more dimensional film stability. These were then reduced to a common 1:24,000 scale on stable-base Mylar. Maximum estimated photogrammetric reproduction errors and errors that result from slight misalignments on the map printing press at the 1:24,000 scale are $\pm$39.5 feet ground distance (USACE-LAD, 1985). Non-linear and differential shrinkage or stretch in original cloth-backed survey maps are included as photogrammetric errors.

b. Uncertainty Caused by Natural Phenomena. Beaches are among the most dynamic of landforms. Shoreline position varies on all scales of time. The MHW line may move horizontally 1 to 10 ft or more between the low and high tide in a single day. It may move miles over a period of 10's of thousands of years as sea level rises or falls. For most coastal planning and engineering purposes it is desirable to establish net changes that will occur on the order of days to 50-100 years. The change of most interest in that which is irreversible over a specified period of interest, i.e., the net trend in shoreline advance or retreat over the life of a coastal management plan or structure. Among its applications the net shoreline change rate is used to establish building setback lines, to estimate long term requirements for beach nourishment, to manage the beach sand resource, and in the design of coastal structures.

When summed, reversible advances and retreats of the shoreline equal zero, i.e. advances are balanced by retreats. Reversible shoreline excursions cannot be established using the shoreline change maps. Reversible shoreline changes, such as those that occur in a few day's time as a result of a wave storm, or seasonally as the incidence of wave storms in California increases (usually autumn and winter) and decreases (usually spring and summer), may be larger than a 50 to 100-yr net change in shoreline position. The net change in shoreline position in a specified period is the change that occurs when the reversible component of shoreline change is removed. From a practical perspective it is desirable to establish the reversible horizontal excursion of the shoreline for the design of most shore protection devices. When the most landward position of the shoreline is established along with the net trend in that position, the scale of protection provided by a beach may be quantified.

Clearly, in using the shoreline change maps to establish and interpret net shoreline change trends, reversible changes must be considered. They constitute the most important uncertainty in establishing net shoreline change rates.

While net shoreline change rates generally average ± 1 to ± 5 ft/yr, the maximum reversible seasonal change in the MHW line of southern California is probably 10 to 100 times as much. During a two-year period that was not abnormally stormy, Nordstorm and Inman (1975) surveyed three parallel, west-facing range lines along a straight shore at Torrey Pines, north of La Jolla. They developed a data set from which the MHW line movements shown in Figure 2 were extracted. The horizontal and reversible movement of the MHW line varied from 75 to 125 ft in that two-year period. The MHW line was usually most advanced in September and October. It retreated to its landward limit between January and April. From about the beginning of April the MHW line advanced as sand moved shoreward. Autumn high waves carried it seaward again, beginning the cycle anew.

Based upon the data presented in Figure 2, reversible shoreline changes within the study area can reasonably be expected to vary over the period of a year by 80-125 ft (or more). The Torrey Pines data are for a limited geographic area and a limited time period. They probably represent a seasonal range that is near the maximum for southern California because the range lines are just north of Scripps and La Jolla Submarine Canyons. Refraction over the canyons focus' wave energy at and near the range lines.

Seasonal reversible excursions in the MHW shoreline as shown in Figure 2, can partially or completely mask a net change in shoreline position. For example if one survey at Torrey Pines had been made in April, and the following survey, many years later, had been made in September, over 100 ft of the shoreline position change would likely have been the result of seasonal and reversible movements. This uncertainty must be considered even though the strong and repetitive seasonal cycle in Figure 2 cannot be assumed.

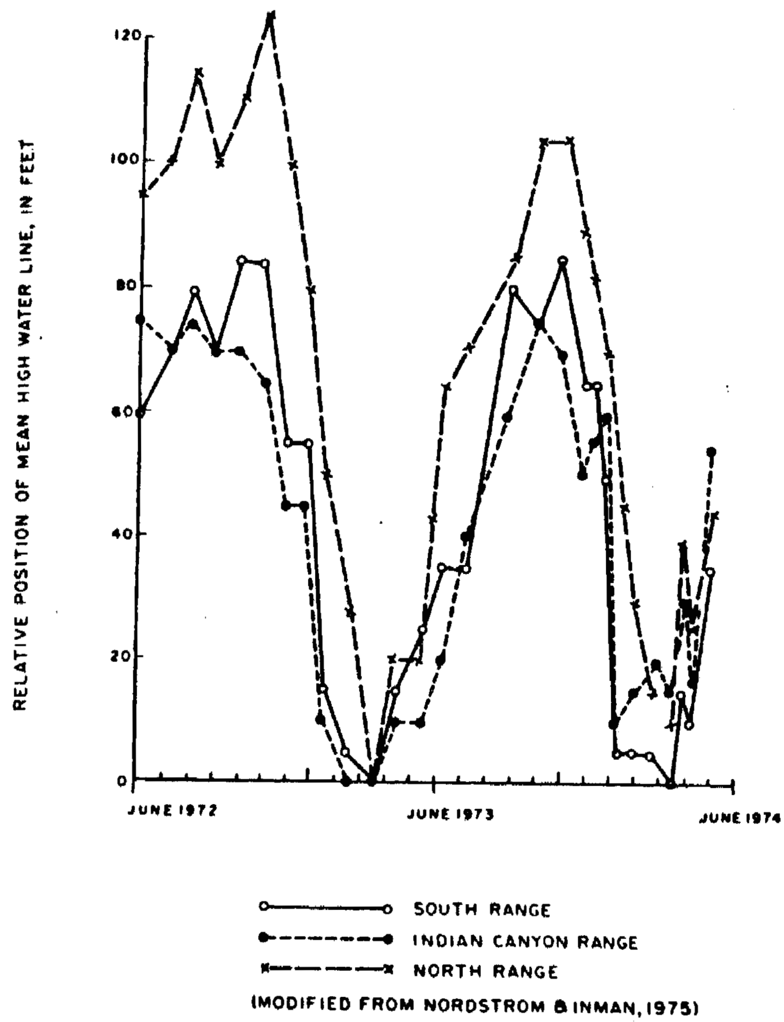

Figure 2. Mean High Water shoreline positions at three ranges across Torrey Pines Beach, La Jolla, California, showing seasonal fluctuations of up to 125 feet.

The cycle of reversible change is usually similar at nearby locations. Longshore trends in net shoreline change between surveys will often provide useful data, even though the magnitude of the net change is questionable because it is within the maximum limits of uncertainty. This is an important point because it identifies a use of the data to establish spatial trends in shoreline behavior when trends in time cannot be quantified.

2. Practical Range of Uncertainty. Comparisons made between data obtained from the NOS maps and data from other sources show the practical uncertainty range is about half the maximum range or about 60 ft. The 60-ft practical range is a best guess based on field data in the study area. MHW shoreline positions from aerial photographs in the Newport and Oceanside Littoral Cells, Corps of Engineers (1960) profiles in the Silver Strand Littoral Cell, and known shoreline changes at Oceanside, San Onofre and Point Loma were used to estimate the practical uncertainty range.

a. Evidence from the Newport Littoral Cell. A comparison of the MHW shoreline change rate in the Newport Littoral Cell obtained using the NOS maps, and the rate extracted from aerial photographs, indicates good agreement in trend (net advance or retreat) and fair agreement in rate as shown on Figure 3. The NOS map rate was obtained using shorelines surveyed in 1959, 1972 and 1982. The aerial photographs used to obtain the shoreline change rate from the 1959-1982 period were taken in 1957, 1960, 1973, 1974, and 1985. The Newport Littoral Cell was selected for the comparison because reaches within it experienced both advance and retreat, most changes between map surveys were larger than the maximum uncertainty range, and quite a bit is known about shoreline behavior in the cell.

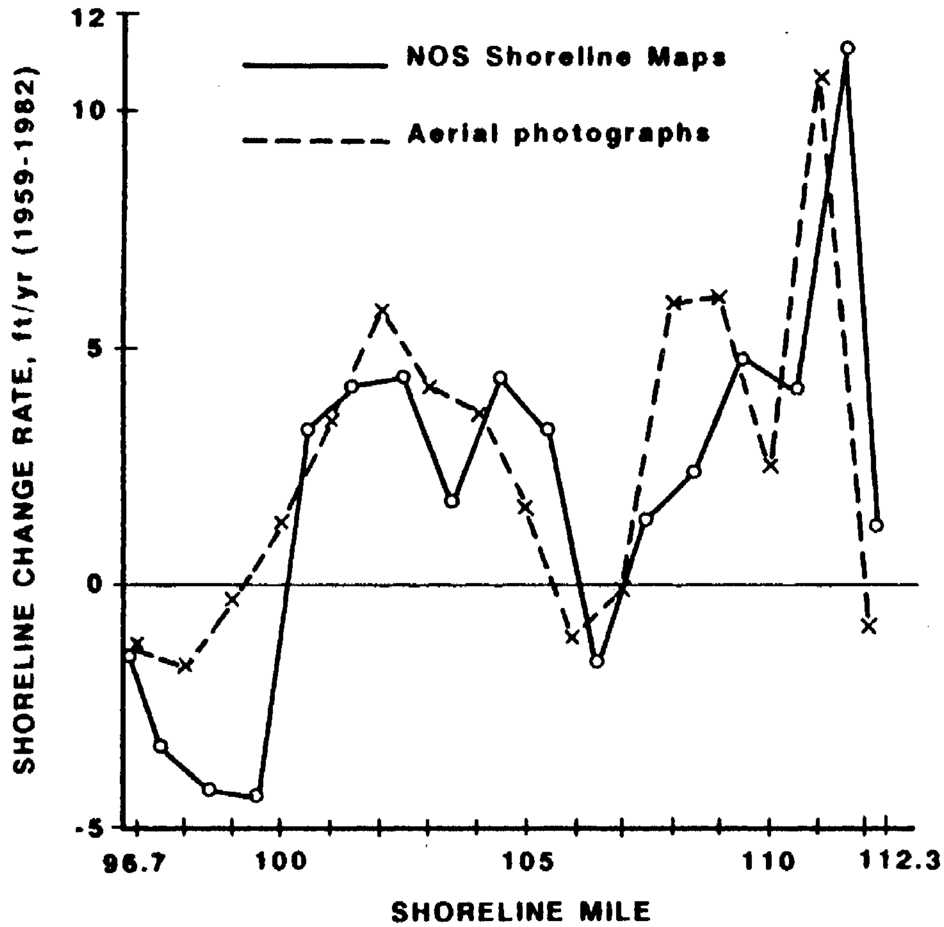

Figure 3. Comparison of MHW shoreline change rates in Newport Littoral Cell using NOS shoreline maps and aerial photographs; period of coverage is 1959 to 1982.

Seasonal and other reversible movements of the MHW shoreline were not adjusted (nor was there a method to do so) before determining the net shoreline change rates shown in Figure 3. All uncertainties inherent in using the NOS maps and aerial photographs to establish net shoreline change rates are therefore present. The map surveys and aerial photographs were not obtained in the same years, nor the same seasons. The net change rate is that which occurred between 1959 and 1982 so a difference of 1 ft/yr is equal to a difference in shoreline position of 23 ft.

The alongshore trend in shoreline advance and shoreline retreat is clearly similar for the two sets of data. Seasonal trends and possible errors in surveying and reducing the survey and aerial photograph data do not mask the net 23 yr trends. Therefore, in the Newport Littoral Cell, an analysis of the 1959, 1972 and 1982 map shorelines appears to provide a viable means to establish net trends in shoreline behavior. In addition to qualitatively defining the trends, it appears the net rates of shoreline change can also be estimated using the maps. While neither data set represented in Figure 3 is likely to provide the exact net change rate, the agreement in trend between the two sets, especially where those trends are known to be correct, indicates the 120 ft maximum uncertainty ($\pm$5 ft/yr) is much too large. The maximum difference in the shoreline change rates at Mile 99.5 is 5 ft/yr or 115 ft while the average difference, based on the difference at each of 16 shoreline mile locations, is 1.7 ft/yr or an average 39.4 ft. The mean net shoreline change rate using these data sets varies by $\pm$0.9 ft/yr and the practical uncertainty in shoreline position is about 40 ft.

b. Evidence from the San Clemente Subreach. Four sets of aerial photographs taken in 1973, 1977, 1978 and 1981 were analyzed by the County of Orange (1984) for a coastal reach between Miles 78 and 81, just south of Dana Point (Fig. 4). Differences in average shoreline position by 1-mi long compartments obtained from the aerial photographs, and from the NOS maps, for the period 1972 to 1982 are at Table 2. In all compartments the shoreline advanced. Table 2 shows the results of a weighted linear average with the 1973-1981 position change obtained using the photographs extended to cover the period of the maps.

The shoreline change trend was the same in each 1-mi reach for each data set. A comparison of the data sets indicates the difference in net shoreline position between 1972 and 1982 averaged 33 ft. Shoreline position changes obtained from the aerial photographs were consistently larger in the 1972-1982 period. The trend is consistent with what actually happened in that 10-yr period. The magnitude of the shoreline advance more than doubles from east to west in both data sets (Table 2) with a difference of 20 to 50 ft.

c. Evidence from the Silver Strand Littoral Cell. A comparison of Corps of Engineers survey data and NOS map data from the Silver Strand Littoral Cell also indicates the practical uncertainty range is considerably less than the maximum uncertainty range. The Corps of Engineers (1960) surveyed a number of shore-normal profile lines between 1937 and 1956 (or 1954) before and after a large quantity of beachfill advanced the shoreline south of Coronado. A comparison of MHW shoreline positions obtained using those data, and shoreline positions on the NOS maps, is illustrated in Figure 5.

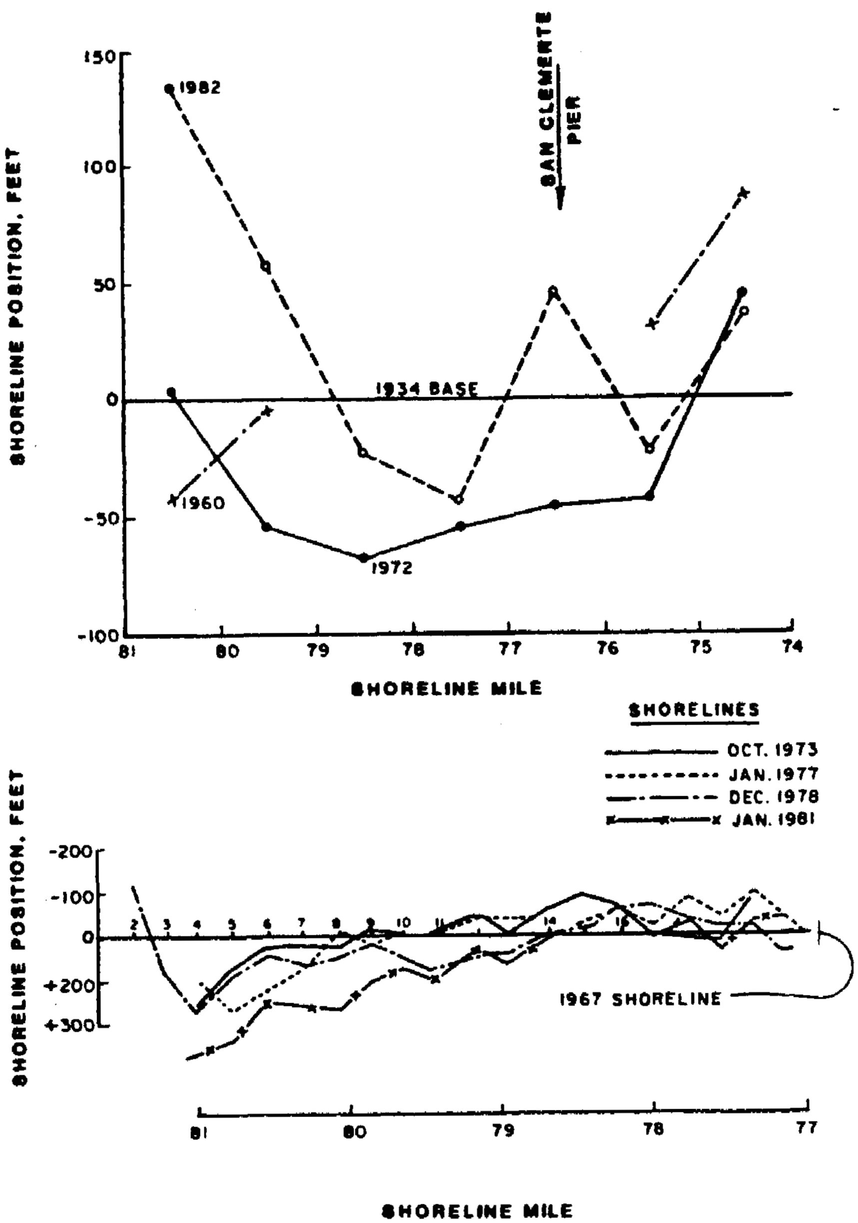

Figure 4. Shoreline position changes in San Clemente Subreach; upper diagram is NOS data, lower diagram is from aerial photographs; large shoreline advance north of Mile 79 shown on both sets of data was probably caused by a reduction in net longshore sediment transport rate because of wave sheltering by Dana Point Harbor which was finished in 1968.

Table 2. Shoreline Position Differences at Capistrano Beach Obtained Using NOS Shoreline Maps and Aerial Photographs

Shoreline Mile:	78-79	79-80	80-81
DATA SET	DIFFERENCE IN SHORELINE POSITION, FT		
(1) NOS map (1972-1982)	+45	+110	+130
(2) Aerial Photographs (1973-1981)	+60	+105	+145
(3) Aerial Photographs (1972-1982)[1]	+75	+130	+180
(4) Difference (3)-(1), feet	30	20	50

Shoreline change trends evidenced in the two data sets are remarkably similar away from the beach that was filled. The restored reach is strongly impacted by artificial beach fill in the early and mid-1940's (Moffatt & Nichol, Engineers, 1987) before the beachfill equilibrated. Even though the NOS and Corps of Engineers data were collected in different ways and at different times of the year, by 1954 the difference in cumulative shoreline change for the two data sets, after the fill equilibrated, averaged about 15 ft (range -40 to +90 ft). The total uncertainty in using the NOS shoreline maps (with the reasonable assumption the Corps field surveys are accurate at MHW elevation) at the Silver Strand is in the range 20-40 ft from one survey to the other. Shoreline adjustment was rapid following the 1941-1946 period of beach restoration. As shown in Figure 5, by 1954 the 1937-1946 rate of change in shoreline position had returned to nearly the 1933-1960 NOS-map rate for those locations strongly affected by the beachfill.

d. Evidence from the Oceanside Area. Map shorelines at Oceanside have exhibited large fluctuations in position since 1888. Away from the reach significantly influenced by large sediment discharges in the San Luis Rey and Santa Margarita Rivers, and away from Oceanside Harbor, five map shorelines all were within a 60-ft wide envelope. Historic evidence indicates the shoreline actually was within this envelop (Kuhn and Shepard, 1984). Further supporting that uncertainty envelop is the change that took place north of the harbor between 1934 and 1960. Breakwater construction, completed in 1942, caused a fillet to form to about 5.5-mi north of the harbor. This caused the shoreline to advance over the northern 2-mi long reach that previously migrated within the 60-ft envelope. North of where the fillet ended the 60-ft maximum envelope of shoreline excursion continued. South of it a new 60-ft wide envelope formed on the fillet, but it was approximately 100 ft seaward of its earlier position. The fillet shoreline became stable in the 1960-1982 period.

e. Evidence from San Onofre. San Onofre Nuclear Generating Station was constructed between the NOS survey years of 1972 and 1982. Over the map years of 1888, 1934, 1960 and 1972, the shoreline envelope there was about 60 ft. The seawall at the generating station caused the shoreline to advance and by 1982 the map shoreline was 150 ft seaward to the north and 60 ft seaward to the south of the earlier shorelines. This suggests the earlier shorelines

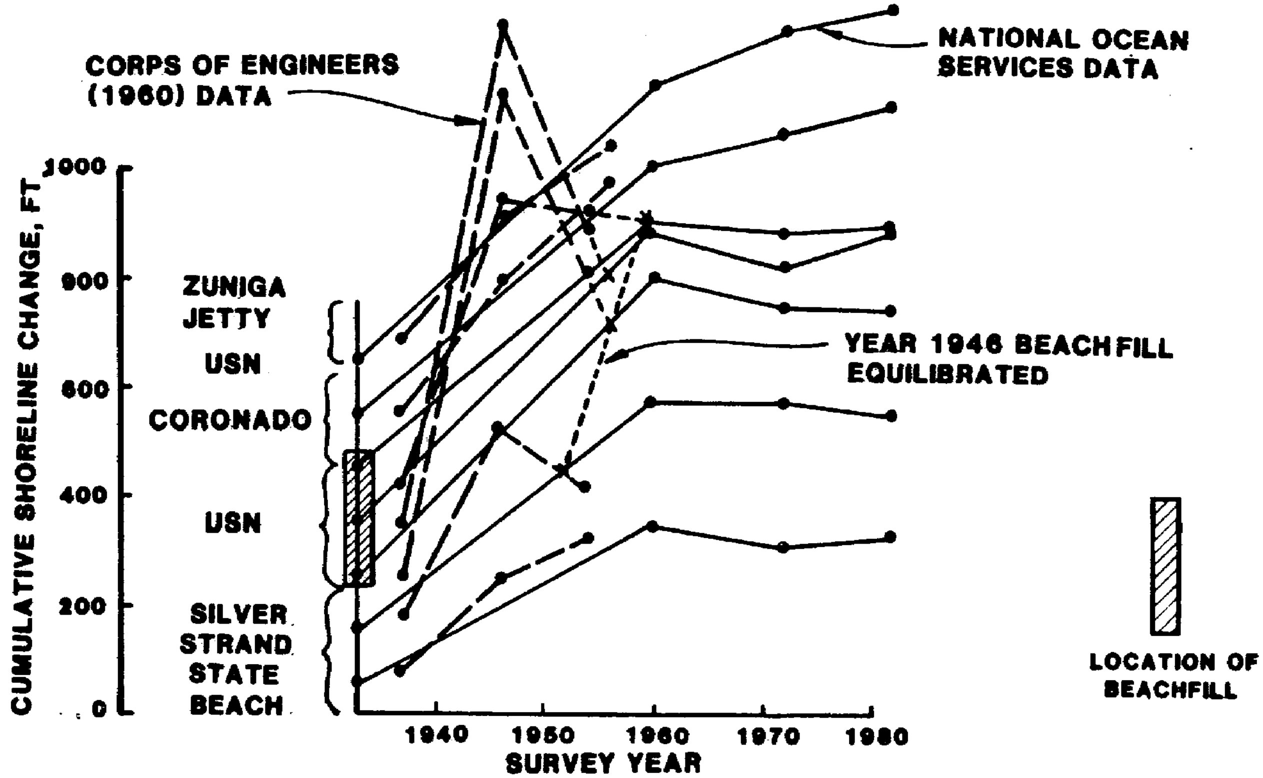

Figure 5. Comparison of net MHW shoreline positions in the Silver Strand Littoral Cell using NOS shoreline maps and Corps of Engineers profile (shore-normal) data for the period of 1937-1956; vertical axis references shoreline mile north of US-Mexico border.

actually moved within a 60-ft wide envelope, and that the envelop was only exceeded when the seawall perturbed the local beach.

f. Evidence from Point Loma. The Point Loma reach (Miles 16-22) is backed by a seacliff without a continuous fringing beach. Kennedy (1975) estimated the seacliff retreat rate along this reach was 0.5 in/yr. Assuming the base (and MHW line) of these seacliffs retreated at the measured seacliff retreat rate, the average retreat in the 49 years (1933-1982) for which NOS shoreline data are available would be about 2 ft. This is much less than the net shoreline retreat that could be obtained using the NOS shoreline change maps. The measured average retreat in this reach, based on NOS map data between 1933 and 1982, was less than 20 ft or (0.4 ft/yr).

3. Summary. The practical, or useful, range of uncertainty in applying the shoreline map data to establish net shoreline changes appears to be about half the maximum possible uncertainty. As shown in Table 3 the average difference between shoreline changes obtained empirically using NOS maps and shoreline changes obtained in other ways averages less than 60 ft. The maximum difference at any location was 115 ft. For practical application an uncertainty range of 60 ft appears reasonable. This range can and should be evaluated when physically-realistic alongshore or temporal trends in shoreline change are discernible, or when a set of more than two shorelines are available.

TABLE 3. Comparison of NOS Map Shoreline Changes with Other Data

Location	Period of Record	Data Used in Comparison	Shoreline Change Differences Maximum, feet	Average, feet
Newport Littoral Cell	1959-1982	aerial photographs	115	40
San Clemente Subreach	1972-1982	aerial photographs	50	33
Silver Strand Littoral Cell	1937-1956	Corps of Engineers surveys	85	15
Oceanside Area	1888-1982	historic accounts, evolution of fillet at harbor	60	<60
San Onofre	1888-1982	change in shoreline behavior after nuclear generating station was constructed	60	<60
Point Loma	1933-1982	measured seacliff retreat where a beach is absent	20	20

III. INTERPRETATION OF SHORELINE DATA

Shoreline change data are presented in this section. Qualitative and in some instances semi-quantitative interpretations of shoreline behavior are given for reaches where changes in shoreline position exceed the practical uncertainty of 60 ft. This interpretive section describe historic shoreline changes along the study reach starting in the south at the U.S.-Mexico border.

1. U.S. Part of Silver Strand Littoral Cell. The U.S. portion of the 16.4-mi long Silver Strand Littoral Cell lies between Mile 0.0 and Mile 13.6 (Fig. 6). It includes the shorelines of the North Island Naval Air Station, Coronado, the Silver Strand, the Naval Radio Station and Imperial Beach. The Mexico portion of the cell, not discussed here, extends 2.8 mi south of the border and includes all of Playas De Tijuana. A natural headland that appears to be a near-complete littoral barrier forms the southern boundary of the cell in Mexico. The north end of the cell is Zuniga Jetty located at the east side of the entrance of San Diego Bay. A sediment budget analysis of the cell that includes the reach in Mexico is available in Moffatt and Nichol, Engineers (1987).

The plan shape of the Silver Strand shoreline and orientation are dominated by Point Loma. Deepwater waves approaching from the north to northwest and to some extent the west quadrants are blocked, refracted and diffracted by Point Loma. Their approach direction at the time of breaking controls the longshore transport of sediment such that the hooked planform shown in Figure 6 results. A bathymetric high centered on Mile 2, the delta of the Tijuana River, produces a smaller, secondary hooked-shape to the south.

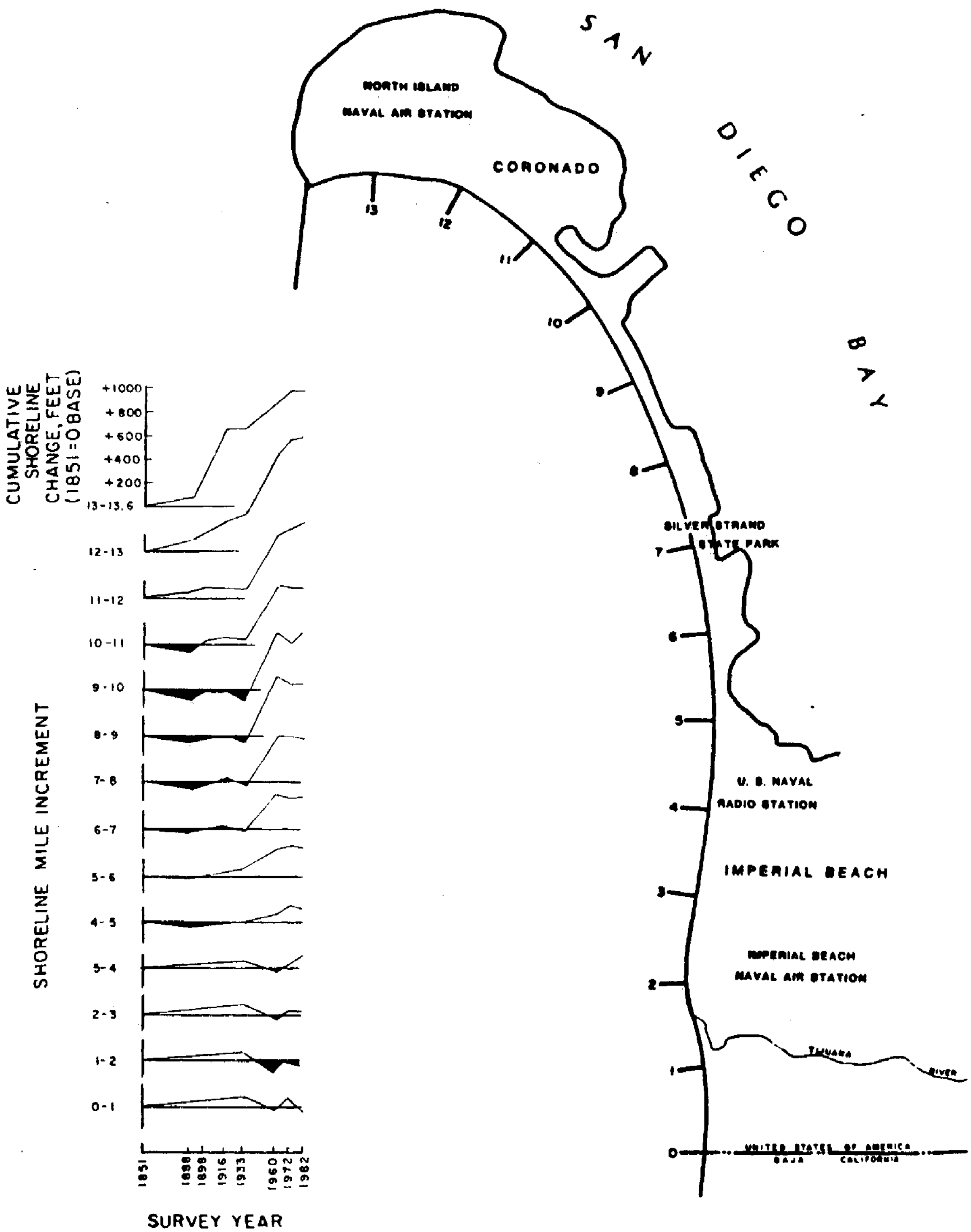

Figure 6. Cumulative changes in shoreline position between 1851 and 1982, averaged by mile, for the Silver Strand Littoral Cell (from Moffatt & Nichol, Engineers, 1987).

Elevations are less than 20 ft (MHW) in the U.S. part of the cell except at the southern end where a seacliff, 10 to 30-ft high, extends to about 0.2 mi north of the border. The seacliff terminates at the floodplain of the Tijuana River. Tijuana Lagoon, a tidal salt marsh, occupies that floodplain. The Tijuana River is the only consequential river-source of sand to the cell, although several ravines enter at Playas de Tijuana. Imperial Beach is situated as a low terrace north of the Tijuana River floodplain and south of San Diego Bay. The Silver Strand is a narrow barrier spit that separates San Diego Bay from the ocean. It forms the central portion of the cell and connects Coronado Island to Imperial Beach. Coronado Island averages 10 to 20 ft in elevation (MHW).

Shore protection and stabilization structures at Imperial Beach and Coronado are listed in the order they were constructed in Table 4. In 1888, the Hotel Del Coronado was the first major building constructed on Coronado Island. Zuniga Jetty, the first coastal structure to have an impact on shore behavior was begun in 1893. The completion of the last extension of Zuniga Jetty in 1904 somewhat enhanced the wave shadow cast by Point Loma.

Beach replenishment projects, also in chronological order, are listed in Table 5. Beach replenishment has had a major impact on shoreline behavior since the early 1940's. A total of over 34 x 10^6 yd^3 of beachfill has been placed. About 26 x $10^6 yd^3$ was dredged from San Diego Bay and pumped to the coast south of Coronado in 1946. It is the largest volume of beachfill ever placed on a beach at a single time in the U.S.

Water retention and flood prevention structures on the Tijuana River and its tributaries (Table 6) have had a major impact on the volume of sediment

TABLE 4. Chronology of Jetty and Groin Construction-Silver Strand Littoral Cell

STRUCTURE	LOCATION	DIMENSIONS	YEAR CONSTRUCTED	PURPOSE
Zuniga Jetty	M 13.6[1]	7500-ft long	1904 (began 1893)	entrance stabilization for navigation purposes
Curved groin, Hotel del Coronado	M 10.0	1400-ft long	1897 (extended in 1900)	create a small craft harbor
Coronado Seawall (rock)	M 11-12	5200-ft long	1906-1907	shore protection
Revetment, Imperial Beach	M 3.0	1000-ft long	1957	shore protection
North groin, Imperial Beach	M 3.8	600-ft long, 720-ft long	1959 extended to 1963	shore stabilization
South groin Imperial Beach	M 3.5	400-ft long	1961	shore stabilization
Pier, Imperial Beach	M 4.5		1963	recreation
Steel sheet pile bulkhead, Naval Radio Station	M 4.5	600-ft long	?	shore protection

[1]M = mile north of U.S.-Mexico border

available in the lower reaches of the river and in the capacity of the lower river to move sediment during floods. Combined, these structures control 1225 mi^2 or 70 percent of the watershed.

TABLE 5. Chronology of Beach Replenishment Projects - Silver Strand Littoral Cell[1]

FILL YEAR	FILL VOLUME, CUBIC YARDS X 10^3	PLACEMENT LOCATION SHORELINE MILE	REFERENCE
1941	2,260	12.6-13.6	Corps of Engineers
1946	26,200	8.8-10.8	Shaw (1980)
1967	40	10	Shaw (1980)
1976	3,500	8.8-10.8	Shaw (1980)
1977	1,100	2.5-3.5	Shaw (1980)
1985	1,100	9.5-10.2	Spencer (pers. comm, 1986)

[1]Total beachfill volume placed through 1985 is 34.2×10^6 yd^3

TABLE 6. Chronology of Dam Construction on Tijuana River

DAM	YEAR COMPLETED	AREA UPSTREAM OF DAM, MI^2
Morena (U.S.)	March 1910	114
Barrett (U.S.)	January 1921	250
Rodriguez (Mexico)	September 1936	1016

The first shoreline survey was made in 1851 and 1852. Since then there have been seven other shoreline surveys at various locations in the Silver Strand Cell. Surveys of the complete U.S. portion of the cell were made in 1851, 1933, 1960, 1972 and 1982. Cumulative changes in shoreline position are shown in Figure 6 based on all surveys. They are shown in Figure 5 for selected surveys after 1933. Shoreline position changes north of Mile 4 show the major effects of the beach replenishment programs in the 1940's. Figure 7 and Table 7 illustrate shoreline change rates between different survey periods along the U.S. portion of the littoral cell.

Shoreline behavior shown on Figures 5, 6 and 7 suggest:

(1) Sand transport in the periods 1933 to 1960 and 1972-1982 was in a net northward direction. The south end of the cell lost sand. This occurred even though there might have been an addition of sand from the Tijuana River source.

(2) At all times the shoreline prograded at Zuniga Jetty (about Mile 11.5 to Mile 13.6) except between 1972 and 1982 when the shoreline there was stable. This suggests alongshore transport in this northern reach is always in a net north direction. Net shoreline advance in the north was occurring before the jetty was constructed.

(3) From 1960 to 1972, the shoreline at the south end of the cell advanced suggesting the net direction of transport in the lower mid-cell to the U.S.-Mexico border was to the south.

(4) Shoreline changes between 1851 and 1933 were such that the shoreline at the south and north ends of the cell advanced while the shoreline in the middle of the cell retreated slightly. The Tijuana River was the major source of sand in this period. North of the river outlet, net transport was likely to the north. The sediment volume made available as a result of river

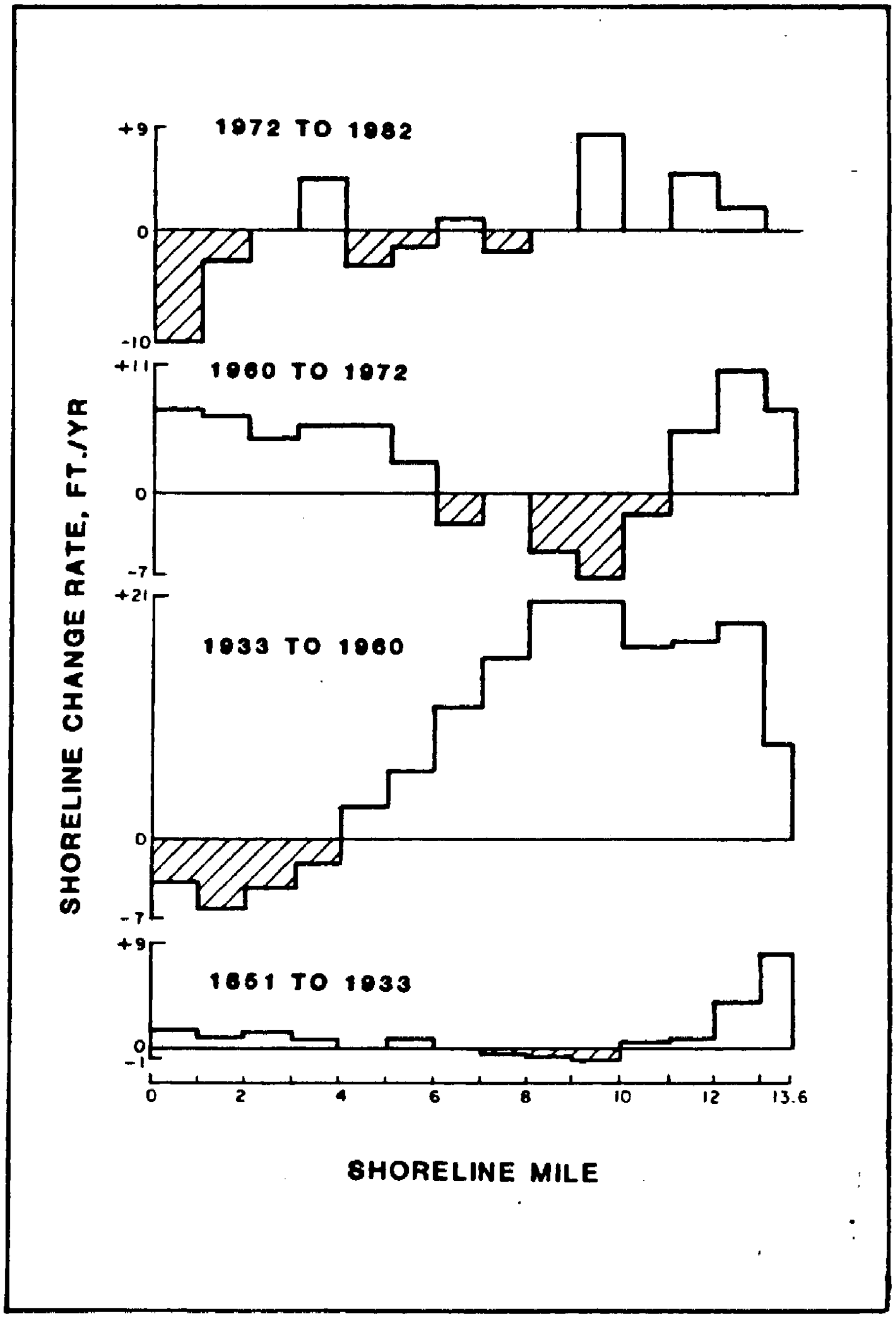

Figure 7. Shoreline change rates by survey period; the 1933 to 1960 shoreline advance north of Mile 4 was mostly the result of the artificial creation of new beach between Mile 8.8 and 10.8 in the 1940's.

TABLE 7. Shoreline Change Rates Between Shoreline Surveys, Silver Strand Littoral Cell, ft/yr (average)[1]

SHORELINE						SHORELINE SURVEY DATES				
INTERVAL	1851.5	1851.5	1888	1888	1888	1898.5	1916.5	1933	1960	1972
Mile	1888	1933	1898.5	1916.5	1933	1916.5	1933	1960	1972	1982
0 to 1		+1.2						-4.0	+7.1	-10.0
1 to 2		+0.9						-6.1	+6.6	-2.9
2 to 3		+1.1						-4.4	+4.6	0.0
3 to 4		+0.7						-2.2	+5.8	+4.5
4 to 5	-1.2				+1.0			+2.7	+5.8	-3.5
5 to 6	-0.2				+1.8			+5.9	+2.5	-1.6
6 to 7	-0.8			+1.8			-1.5	+11.1	-2.9	+1.0
7 to -8	-1.6			+2.8			-2.7	+15.6	0.0	-2.0
8 to 9	-1.4			+1.8			-3.0	+20.7	-5.0	0.0
9 to 10	-2.3		+7.1			0.0	-4.2	+20.7	-7.1	+8.5
10 to 11	-1.9		+8.6			+1.9	-0.6	+16.9	-1.7	0.0
11 to 12	+1.4		+3.8			-1.1	0.0	+17.0	+5.4	+5.0
12 to 13	+2.9		+5.2			+5.5	+3.9	+18.7	+10.8	+2.0
13 to 13.65	+2.2		+20.0			+20.6	+0.6	+8.1	+7.5	0.0

[1]National Ocean Services data

discharge was probably balanced in the long term by the capacity of the waves to carry the sand away from the delta.

(5) Before construction of Zuniga Jetty, Zuniga Shoal extended at least a mile offshore and was reportedly exposed at low tide (Leeds, 1938, p. 3). During and after the jetty was constructed across the shoal, the shoreface profile east of the jetty steepened. From 1893 to 1898 the shoreline from Mile 13.0 to Mile 13.6 advanced over 200 ft. During the remainder of the construction period (until 1904) and then until 1916, it advanced an additional 370 ft. The advance declined greatly after 1916. In 1900, erosion exacerbated by the jetty had extended downcoast to Mile 12.0. Severe storm damage occurred at Mile 11.0 (Hotel Del Coronado) in 1905. Maximum erosion following jetty construction was near Mile 11.5.

(6) The 1941-1946 beach replenishment program produced a major advance of the shoreline between Miles 4.5 and 13.6 as evidenced in the data for the 1933-1960 survey period (Fig. 5).

(7) A large net advance of the shoreline between 1941 and 1976 at the north end of the cell (Miles 9 to 13) was the result of large quantities of beachfill placed between Miles 8.8 and 10.8.

(8) Following the beachfill adjustment period of 1946-1960 (14 years or less) shoreline behavior in those reaches where the shoreline had previously been stable or recessional returned to the pre-1933 stable or recessional conditions (Miles 4.5 to 10.5). Those reaches that had experienced shoreline advance before 1933 continued to advance at near the same rate (Miles 10.5 to 13.6). The post-beachfill rates continued even

though the shoreline in 1960 was 300 to almost 700 ft seaward of the 1933 shoreline.

2. Mission Bay Littoral Cell. This 13.7-mi long cell (Fig. 8) lies north of the entrance to San Diego Bay (Mile 15.8) and south of Point La Jolla (Mile 29.5). The only man-made structures that impede the longshore movement of sand in the cell are jetties at the entrance of Mission Bay, a flood control jetty at the outlet of the San Diego River and a groin at Ocean Beach. In 1950, the 3300-ft long north jetty at the entrance to Mission Bay was completed. At the same time the south entrance jetty (middle jetty) was constructed to a 3800-ft length. In 1970 it was extended to 4280 ft. The middle jetty also serves as the north flood-control jetty of the San Diego River. In 1950, the south flood-control jetty at the river outlet was constructed to a length of 1500 ft and in 1970 it was extended to 2070 ft. In recent years sand from Ocean Beach has moved north and around the south jetty and formed a barrier beach in the outlet of the San Diego River. This barrier sometimes extends completely across the river entrance. At other times tidal and river flow maintains a small opening south of and against the middle jetty. In 1955 a 500-ft long groin was constructed at Ocean Beach to slow the northward transport of beach sand. A sediment budget analysis of the sandy central part of the cell is available in Everts et al (1987, draft).

Since 1948 beach replenishment has added about 1.6×10^6 yd^3 of material to the littoral cell. Table 8 shows the volume and location of the seven replenishment projects. After 1950, the source of beachfill was the channel between the Middle and North Jetties. An average 2.9×10^4 yd^3/yr were placed in the Mission Beach and Ocean Beach Subcells between 1951 and 1987. After 1951, a total of 3.7×10^5 yd^3 were placed on Ocean Beach and 9.6×10^5 yd^3 were

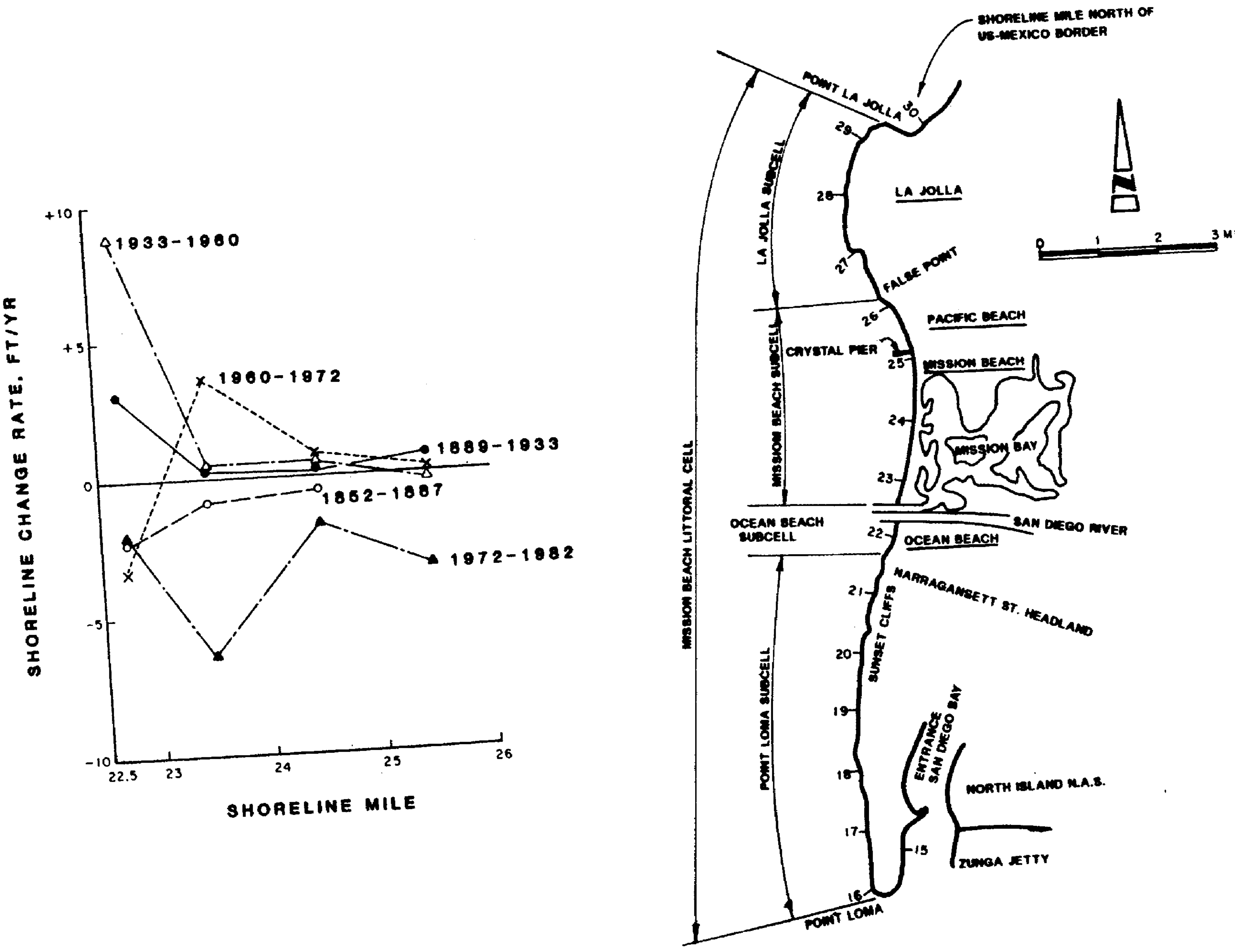

Figure 8. Mission Bay Littoral Cell showing shoreline change rates between

TABLE 8. Beach Replenishment, Mission Bay Littoral Cell

LOCATION	QUANTITY PLACED, yd^3	PLACEMENT DATE	REMARKS	REFERENCE
Ocean Beach	67,000	May 1950	migrated north and filled in mouth of San Diego River	USACE-LAD (1970)
Ocean Beach	275,000	June 1959	contained at north end by groin	USACE-LAD (1970)
Ocean Beach	30,000	1984	placed south of groin	Castens, Corps of Engineers records (pers. comm)[1]
Pacific Beach	230,000	June 1973	reportedly migrated south	Shaw (1980)
Mission Beach (2000-ft long reach at north end)	600,000	1948	beachfill from Mission Bay dredging; beachfill transported south, by 1958 shoreline had returned to 1948 position; shoreline retreted 200 ft in reach south of Crystal Pier	USACE-LAD (1964)
Mission Beach	150,000	1958	beachfill from Mission Bay dredging	USACE-LAD (1964)
Mission Beach	246,000	1984	beachfill source, was entrance to Mission Bay, after placement near amusement park beachfill moved north.	Castens, Corps of Engineers records (pers. comm)[1]

[1] in conflict with Flick et al, (1986) who stated 276,000 yd^3 were dredged from the entrance channel, with one-half placed on Mission Beach and one-half placed on Ocean Beach.

placed on Mission Beach. According to survey and dredging records (Castens, pers. comm, 1987, Corps of Engineers, Los Angeles District) channel shoaling was greatest opposite the junction of the ocean shoreline and the north and middle jetties. The shoal area in the channel extended to the end of the Middle Jetty and the same distance landward. On the Mission Beach side of the channel the shoal area extended about 1000-ft seaward and landward of the nearby location where the shoreline meets the jetty. Approximately two-thirds of the shoaling occurred against the Middle Jetty and one-third against the North Jetty. The shoaling rate in the 1960-1984 period was nearly constant at 2.1×10^4 yd^3/yr.

Point Loma and Point La Jolla are at major changes in shoreline orientation. Both points and the interviewing cell are offset seaward to the west of the regional trend of the coastline and of adjacent littoral cells by one to 3 miles as shown in Figure 1. The average orientation of the shoreline in the littoral cell is 355 degrees, or more nearly north-south than the shoreline of either the Oceanside Littoral Cell to the north or the Silver Strand Littoral Cell to the south.

In addition to Point Loma and Point La Jolla, natural and artificial headlands also restrict the alongshore movement of littoral sediment within the Mission Bay Cell. These headlands, the Narragansett Avenue headland, the combined entrance jetties at Mission Bay and the outlet of the San Diego River, and False Point (Fig. 8), separate sandy beach areas from each other and from predominantly seacliff shorelines. For analysis purposes they conveniently separate the littoral cell into four subcells. From south to north they are:

a. Point Loma Subreach (Mile 15.8 to 21.7). This reach is backed by steep seacliffs. Beaches are small and intermittent. Sand apparently comes from the north, passes along this subreach, and is accumulating off Point Loma at a rate of 5 to 8 x 10^3 yd^3/yr (Moffatt & Nichol, Engineers, 1987). All beaches are contained between headlands of resistant rock. Many contain quantities of gravel and cobbles. Shoreline changes have been small and all net changes in shoreline position have been within the practical error bounds of the maps. Seacliff retreat problems, however, exist. Wave scour at the base of the seacliffs and subaerial erosion and rock failures above the zone of wave activity are responsible for the retreat. Intensive development at the top of the seacliffs has exacerbated the seacliff retreat problems. Cliff line retreat between 1926 and 1961 has been reported (USACE LAD, 1970) at 1 to 3 ft/yr at some places along the Sunset Cliffs portion of this reach.

b. Ocean Beach Subreach (Mile 21.7 to 22.4). This 3500-ft long reach is presently contained between a natural headland and the south entrance jetty at Mission Bay. Before 1950 the natural entrance of Mission Bay formed the north boundary of Ocean Beach. In 1950 the middle jetty (south entrance jetty at Mission Bay) became the north subreach boundary. The jetty prevents sand at Ocean Beach from moving further north. Sand is delivered to Ocean Beach by the San Diego River, but the volume has been greatly reduced in recent years because of jetty construction and reduced sand discharge in the river. Since 1950, artificial beach replenishment has influenced beach behavior in this sub-reach.

The 1933 map shoreline of the south one-half of Ocean Beach was, on average, about 60 ft seaward of its 1960 position and about 160 ft seaward of its 1972 and 1980 positions. Frautschy and Inman (1954; in USACE LAD, 1986) note the wave shadow created by the jetty modified the longshore sediment transport rate at Ocean Beach, producing accretion at the jetty and erosion at the south end of the reach i.e., the jetty temporarily changed the net longshore transport pattern. Sand moved north until a new plan equilibrium shoreline shape was created. The groin was constructed in 1955 to reduce this northward transport. Between 1960 and 1972 the shoreline retreated an average 100 ft at Ocean Beach.

The net sand volume loss at Ocean Beach between 1960 and 1972 was perhaps 400,000 yd^3, or 35,000 yd^3/yr (10 $yd^3/ft\text{-}yr$, obtained using h_s = 32 ft, l = 3500 ft and ΔS = 100 ft, in Equation 1). Considering the plan area change that occurred between 1972 and 1982, especially near the jetty, the average yearly sand loss in that period was slightly smaller. A decline in the volume of sand reaching the beach from the San Diego River, plus continuing losses to the south around the Narragansett Avenue headland, thence along the coast of the Point Loma sub-reach, plus possible offshore losses, appear to be the cause of the net shoreline retreat.

c. Mission Beach Subreach (Mile 22.5 to 26.1). Mission Beach in the south and Pacific Beach to the north constitute the Mission Beach subreach. (Fig. 8). Its gently concave shoreline extends north from the north Mission Bay Entrance Jetty (Mile 22.5) to a natural headland (False Point) at Mile 26.1. Beach behavior in this reach has been influenced by human intervention in the form of jetty construction and by the artificial placement of beachfill (Table 8).

Shoreline changes in the Mission Bay subreach have been partly within the practical uncertainty bounds of the shoreline data. Change rates are given in

Table 9 and shown on Figure 8. The largest changes occurred near the entrance to Mission Bay. The shoreline was near-stable in other areas before 1972. A net shoreline retreat is indicated for the 1972 to 1982 period, however, the average 21 ft retreat is still well within the uncertainty bound of the data. Overall the data reflect a slight net shoreline advance in the 130-year period comprising the data set. Converted to net sediment volume change (Eq. 1), this would be equal to a net gain of about 5 x 10^5 yd^3. Subtracting the 9 x 10^5 yd^3 artificially placed on the beach before 1982, a natural net loss of 4 x 10^5 yd^3 (about 3,000 yd^3/yr) is indicated between 1851 and 1982.

TABLE 9. Shoreline Change Rates, Mission Beach Subcell[1]

SHORELINE INTERVAL (Mile)	SHORELINE SURVEY DATES 1852-1889	1889-1933	1933-1960	1960-1972	1972-1982
22.5-23.0	-2.2	+3.0	+8.9	-3.3	-2.1
23.0-24.0	-0.8	+0.3	+0.5	+3.6	-6.3
24.0-25.0	-0.5	+0.2	+0.5	+0.8	-1.6
25.0-26.1	ND[2]	+0.7	-0.2	+0.2	-3.3
average	-1.0	+0.8	+1.5	+0.8	-3.5

[1]in feet per year averaged by shoreline interval, and averaged between survey dates

[2]No data

d. La Jolla Subreach (Mile 26.1 to 29.5). The La Jolla sub-reach is backed by seacliffs. It contains a number of popular pocket beaches, i.e., Windansea Beach, Marine Street Beach, Casa Beach and Boomer Beach, to mention a few. Changes in shoreline position on these beaches has been within the practical uncertainty range of the maps. Inman (1953) notes the sand on the La Jolla beaches is of local origin and sediment transport into and out of these pockets is essentially zero. Headland areas are not fronted by beaches.

3. Oceanside Littoral Cell. This 53.5-mi long reach is perhaps the most studied littoral cell in the United States. Net longshore sediment transport is generally thought to be from north to south. Dana Point, the north end of the cell at Mile 83.0 (Fig. 1), is a near-complete barrier to the longshore transport of sand. Point La Jolla at Mile 29.5, the south end, is also a near-complete littoral barrier. Little, if any, sand reaches Point La Jolla, however, because it is deflected into the heads of the Scripps and La Jolla Submarine Canyons (reach from Mile 30 to 32).

This discussion of shoreline changes in Oceanside Littoral Cell addresses subreaches within the cell beginning from its south end. Subreach boundaries have been selected based on geomorphic and cultural features such as river or lagoon entrances, minor headlands, adjacent submarine canyons, seacliffs and harbor structures. Historic conditions at lagoon outlets are discussed last.

Historic shoreline changes in the Oceanside Littoral Cell more often than not were within the practical uncertainty limits of the surveyed shorelines. The Oceanside Subreach, centered on the Santa Margarita and San Luis Rey Rivers and Oceanside Harbor is a notable exception. Very large shoreline advances and retreats occurred at Oceanside in historic time.

a. La Jolla - Torrey Pines Subreach (Mile 29.5 - 35.5). Changes in the map shoreline in this subreach are to some extent related to the behavior of the seacliffs. The presence of submarine canyons have played a role in the evolution of the shoreline. Figure 9 is a location sketch of the southern one-third of the Oceanside Littoral Cell that shows the La Jolla-Torrey Pines Subreach and its shoreline behavior from 1888 to 1982. All the change rates are within the practical uncertainty limits of the data. In the 94-yr period of record, however, the map shoreline trend was an advance averaging 0.7 ft/yr. Much of the map shoreline advance occurred between 1888 and 1933. Shoreline change rates prior to 1972 were quite consistent, especially from Mile 31 to Mile 35, suggesting the movements were real even though they were within the uncertainty range. Map shoreline changes in the 1972-1982 period varied greatly from the earlier net advance.

(1) Seacliffs Subject to Landslides (Mile 31.5-34). The shoreline at this location advanced an average 2 ft/yr between 1888 and 1972 (Table 10, Figure 9). Most of the advance that occurred between 1888 and 1933 appears to have been the result of seacliff slumping. The crest of the seacliff retreated and the toe advanced along much of this part of the subreach. Less significant slumping may be responsible for shoreline advance in the periods 1933 to 1960 and again 1960-1972 with the largest 1960-1972 advance in the Mile 33 to Mile 34 region. From 1972 to 1982 the map shoreline retreated an average 2 to 3 ft/yr.

(2) Seacliffs Not Subject to Major Slumping (Mile 29.5 to 30.0; Mile 31.0 to 31.5; Mile 34.0 to 35.5). These seacliff shorelines extend slightly seaward of adjacent areas, probably because the seacliffs are more resistant to wave attack and subaerial slumping and erosion. All changes in these

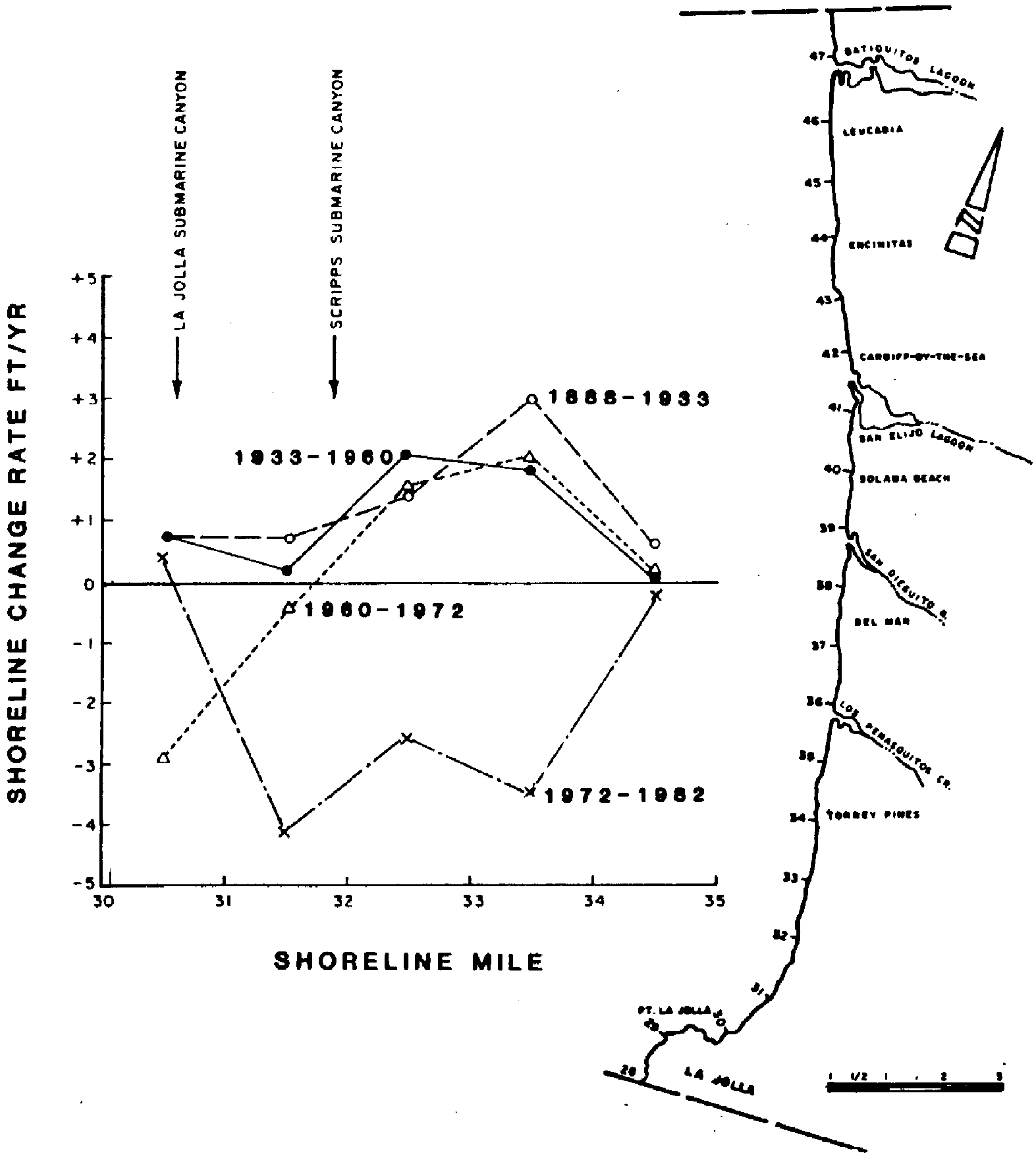

Figure 9. Shoreline change rates between 1888 and 1982 near La Jolla and Torrey Pines at the south end of the Oceanside Littoral Cell.

regions are within the uncertainty bounds of the maps except a one-quarter mile long reach at Mile 35.0. It appears the base of the seacliff was embayed at this location in 1888, but by 1933 a landslide caused by toe failure had removed material from the crest of the seacliff, or a subaerial slump, had deposited it on the beach, thereby straightening the shoreline to that which existed in 1982.

TABLE 10. Shoreline Change Rates, La Jolla - Torrey Pines Subreach Oceanside Littoral Cell[1]

SHORELINE INTERVAL (Mile)	SHORELINE SURVEY DATES 1888-1933	1933-1960	1960-1972	1972-1982
30-31	+0.7	+0.7	-2.9	+0.4
31-32	+0.7	+0.2	-0.4	-4.1
32-33	+1.4	+2.1	+1.6	-2.5
33-34	+3.0	+1.8	+2.1	-3.4
34-35	+0.6	+0.1	+0.2	-0.2
average	+1.3	+1.0	+0.1	-2.1

[1]in feet per year averaged by shoreline interval, and averaged between survey dates

(3) Submarine Canyon (Mile 30.0 to 31.0; Mile 31.5 to 32.0). The shoreline is embayed (concave-seaward shape) landward of the heads of the two submarine canyons. The embayment is most apparent onshore the head of Scripps Submarine Canyon (Mile 31.5 to 32.0). The 1-mi long shoreline near La Jolla Submarine Canyon (Mile 30 to 31) varied within the map uncertainty in the period 1888-1982. Although this indicates a measure of stability, storm-caused retreat of the shoreline has created seacliff retreat problems near Mile 31 (Kuhn and Shepard, 1984). Subsequent post-storm advance returned the shoreline to near its pre-storm location, but the reversible fluctuation in shoreline position created a need for shore protection devices from Mile 30.5

to 31.0. When the beach is wide sand moves into the heads of the canyons; when the beach is narrow littoral sand tends to pass the canyon heads and move downcoast.

Landward of Scripps Submarine Canyon (Mile 31.5 - 32.0) the shoreline advanced between 1888 and 1933, probably as a result of landslides. Since 1933 shoreline position changes there have been within the uncertainty bounds of the maps.

b. Del Mar Subreach (Mile 36.3 to 38.8). This subreach is flanked by Los Penasquitos Creek on the south and the San Dieguito River outlet on the north. Seacliffs back the shoreline from Mile 36.3 to Mile 37.7. The beach in front of the seacliffs is narrow and shoreline changes since 1888 have been within the practical uncertainty limits of the maps (Table 11). From Mile 37.7 to Mile 38.8 the beach is the seaward edge of the San Dieguito River floodplain. This has been an active area. Between 1888 and 1933 new beach was created in fillet form with a shoreline advance of almost 200 ft at the San Dieguito River outlet. The advance declined linearly in an alongshore direction such that no change occurred 1.1 miles to the south.

TABLE 11. Shoreline Change Rates, Del Mar Subreach

SHORELINE INTERVAL (Mile)	SHORELINE SURVEY DATES[1] 1888-1933	1933-1960	1960-1972	1972-1982
36.3-37.0	+1.5	+0.1	-0.1	0.0
37.0-38.0	+0.9	+0.1	-0.1	+0.9
38.0-38.8	+3.8	-1.0	+3.1	0.0
average	+2.0	-0.3	+0.9	+0.4

[1]in feet per year averaged by shoreline interval, and averaged between survey dates

c. Solana Beach Subreach (Mile 38.8-40.6). Except at Mile 39.2, shoreline changes between the San Dieguito River and San Elijo Lagoon were within a range of 80 ft. This is within the maximum uncertainty bounds of the maps from 1888 to 1982. The trend was shoreline advance from 1888 to 1933 and variable advance or retreat thereafter. Kuhn and Shepard (1984) describe the Mile 39.2 location in some detail. In 1888 the shoreline there was at the base of the seacliff. Subsequent shorelines are seaward of the seacliff base, and some of the material comprising those shorelines is talus.

d. Cardiff to Leucadia Subreach (Mile 41.7-46.7). This 5-mi long subreach, which includes the City of Encinitas, is backed by seacliffs its entire length. Beaches are narrow. Shorelines from 1888 through 1972 are within the practical uncertainty bounds of the maps. Interestingly, the 1982 shoreline, except at the northernmost 0.5 miles of the subreach, is seaward of all the other shorelines by an average 180 ft. The location is curious because of its seaward position and near-constant displacement the length of the subreach.

The 1982 shoreline was established from aerial photographs taken in March when the beach may have been wide. Kuhn and Shepard (1984) note early 1982 was a mild wave year compared to preceding abnormally stormy years. In an analysis of 5 years of data Thompson (1987) showed the shoreline was almost stable at Mission Beach and Pacific Beach in the period late summer 1981 to April 1982. Beach width declined an average 65 ft from late summer to spring in each of the other 4 years Thompson considered. Similarily, Flick et al (1986) found that beaches in the spring of 1982 were as wide as they were in the late summer of 1981. The 1981-1982 winter season was very mild and when the March 1982 shoreline was established it was seaward of its mean position in many locations.

e. South Carlsbad Subreach (M47.0 to M50.8). The shoreline south of Mile 50.0 was within the practical uncertainty bounds of the maps from 1888 to 1982. Between Mile 50.0 and Mile 50.8, at the south side of Agua Hedionda Lagoon (Fig. 10), the shoreline advanced between 1888 and 1982 an average 1.5 ft/yr. The 1982 shoreline is far seaward of the 1972 shoreline suggesting the latest shoreline was near its seaward reversible limit, rather than at a seasonal midpoint. The 1888 shoreline is most landward of all shorelines suggesting the effects of storms in 1884-1888 had removed much of the beach sand prior to the 1888 survey.

f. Carlsbad Subreach (Mile 51.4-53.0). Changes in the MHW shoreline in this reach were within the practical uncertainty bounds of the maps between 1888 and 1982 except at the south end where a fillet formed against the north Agua Hedionda jetty after its construction in 1954. The 1960, 1972 and 1982 map shorelines, all located at the same position against the jetty, are 200 ft seaward of the 1934 shoreline.

g. Oceanside Subreach (Mile 53.0-62.8). Shoreline fluctuations in a 10-mi long reach near Oceanside were among the largest on the NOS maps of southern California. These fluctuations were caused by changes in coarse sediment supplied by local rivers and an unsteady longshore sediment transport system. Sediment supply has been and still is governed by cyclic, mostly natural phenomena; the direction and net rate at which sediment is transported alongshore has been permanently changed by structures at Oceanside Harbor.

Shoreline behavior before the harbor jetties were constructed in 1942 was significantly different from subsequent behavior. It is therefore useful to use 1942 as a time boundary. Table 12 is a chronology of events at Oceanside that are of interest when attempting to understand the causes of shoreline change.

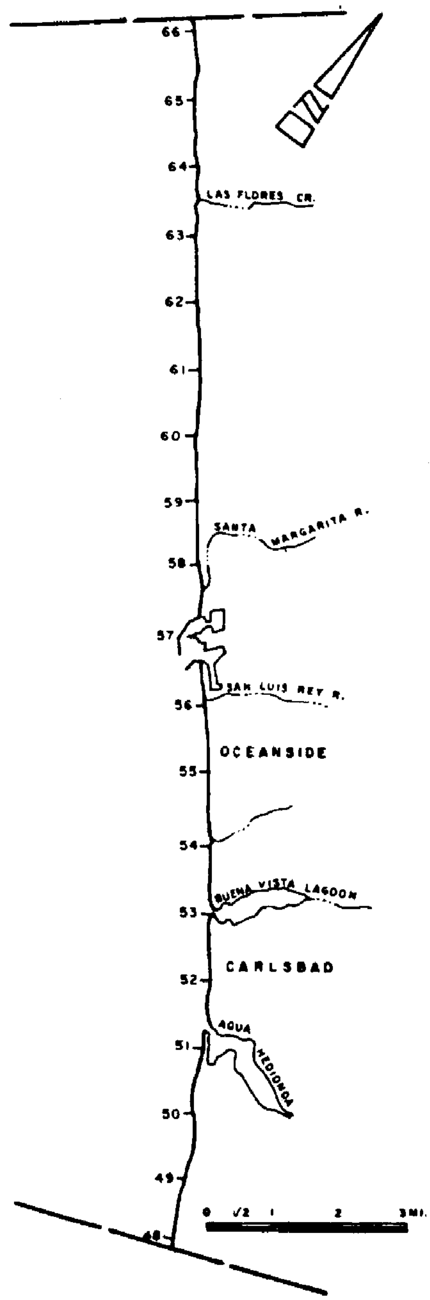

Figure 10. Location map, central portion of Oceanside Littoral Cell.

Table 12. Chronology of Coast-Related Events at Oceanside, 1825 to 1983

1825	Major flooding in southern California
1862	Major flooding in southern California (perhaps largest in historic time)
1842-1883	Dry period, except 1861-62 floods
1884	Major flooding in southern California
1885	Beaches were 100 ft wide near site of present pier; slump material was 50 ft seaward of seacliff (Kuhn and Shepard, 1984, photo)[1]
1887-1888	U.S. Coast and Geodetic shoreline survey
1916	Maximum flow in San Luis Rey River, 95,600 ft^3/sec on 27 January
1922	Henshaw Reservoir constructed on San Luis Rey River (Hales, 1978)
1925	Beach was narrow (Hales, 1978)
1927	Pier and frontage walk constructed
1927	Maximum flow in Santa Margarita River, 33,600 ft^3/sec on 16 February
1931	Wide beach (Corps of Engineers, 1980)
1934	U.S. Coast and Geodetic shoreline survey
1938	Large flood, sand delivered by San Luis Rey River (Troxell et al., 1942)
1939	Oceanside beach was wide (Hales, 1978)
1940-41	Storms (23 Dec 1940 through 7 Jan 1941) erode beaches; seacliff toe at Wisconsin Avenue is cut back (Kuhn and Shepard, 1984, photo)
1942	Del Mar Boat Basin constructed; dredged material used to increase grade around basin (Hales, 1978)
1942-43	Erosion of Oceanside beaches (Hales, 1978)
1944-45	Erosion reduced as harbor entrance fills in (Hales, 1978)
1945	Entrance channel shoaled from a cross-sectional area of 3800 ft^2 to 700 ft^2; 220,000 yd^3 removed and placed as land fill (Hales, 1978)

1945	Erosion of Oceanside beaches following entrance dredging (Hales, 1978)
1946	220,000 yd^3 transported by longshore currents and deposited in entrance channel in 8 months (Hales, 1978)
1949	Vail Dam constructed on Santa Margarita River (Hales, 1978)
1949	Riprap placed along a 1000-ft long reach at Wisconsin Avenue
1942-1952	Shoreline adjacent to harbor entrance advanced as 2.5×10^6 yd^3 (0.8×10^6 yd^3 - north, 1.7×10^6 yd^3 - south) was deposited; Oceanside beaches lost 2.7×10^6 yd^3 (Moffatt & Nichol, Engineers, 1968)
1950-1951	Additional riprap placed near Wisconsin Avenue
1952	Two groins placed at Wisconsin Avenue and 1000 ft south of Wisconsin Avenue
1950's	Seawalls and revetments constructed in Oceanside (Hales, 1978)
1950's	Groins constructed near Wisconsin Avenue (Hales, 1978)
1955	Navy places 800,000 yd^3 of sand south of entrance to boat basin (Hales, 1978)
Oct 1956-Oct	0.8×10^6 yd^3 deposited in lee of jetties; Oceanside beach lost
1959	1.2×10^6 yd^3 (Moffatt & Nichol, Engineers, 1968)
1960	U.S. Coast and Geodetic shoreline survey
Early 1960's	Oceanside Harbor constructed; groin constructed on north side of San Luis Rey River entrance; 4×10^6 yd^3 of sand and cobbles placed south of Harbor entrance in 1963 (Hales, 1978)
1963-1965	Beach erosion continues (Hales, 1978); 0.7×10^6 yd^3 dredged from entrance and placed on Oceanside beaches (Moffatt & Nichol, Engineers, 1968)
1965	Cobbles on Oceanside beaches, most notable at Witherby Street north of pier (Hales, 1978)
1965-Feb 1968	About 0.63×10^6 yd^3 deposited in harbor entrance (Moffatt & Nichol, Engineers, 1968)
1969	Coarse sediment discharged from both rivers
1965-1978	Beach restoration averaged 290,000 yd^3/yr (Weggel and Clark, 1983)
1972	U.S. Coast and Geodetic shoreline survey

1978	Beach sand lost during storms, cobbles thrown into houses, south Oceanside and Carlsbad beaches badly eroded (Kuhn and Shepard, 1984)
1980	Storms erode beach; road damage and seawall collapse along south end of Strand between 12 and 15 February (Kuhn and Shepard, 1984, photos); storm losses estimated at $1.2 x 10^6$
1982	U.S. Coast and Geodetic shoreline survey
1982-1983	Severe beach erosion

[1]reference in parentheses

(1) River Discharge. Shoreline behavior at Oceanside has been greatly influenced by the frequency and volume of sediment reaching the coast from the Santa Margarita and San Luis Rey Rivers. River outlet location is an important factor, especially in recent times, since Oceanside Harbor separates the two river entrances.

Following a high discharge event, large volumes of river-borne sediment is stored in deltas until waves and currents carry it away. Delta protrusions of the 30-ft bathymetric contour off both rivers, shown in 1935 bathymetry in Figure 11, for example, are evidence of past floods, probably the flood of 1927. The absence of a noticable a river delta protrusion at the 60-ft contour suggests those deltas built beyond 30-ft depths, but not to 60 ft. The absence of protruding bathymetric contours in water shallower than 30 ft suggests that by 1935 longshore currents had carried away most of the sediment deposited in the flood of 1927.

Sediment discharge to the ocean by the Santa Margarita River differs in two ways from discharge in the San Luis Rey River. First, coarse sediment discharge is higher in the San Luis Rey River. The time of high sediment discharges varies as well. In the 20th Century, for example, the maximum

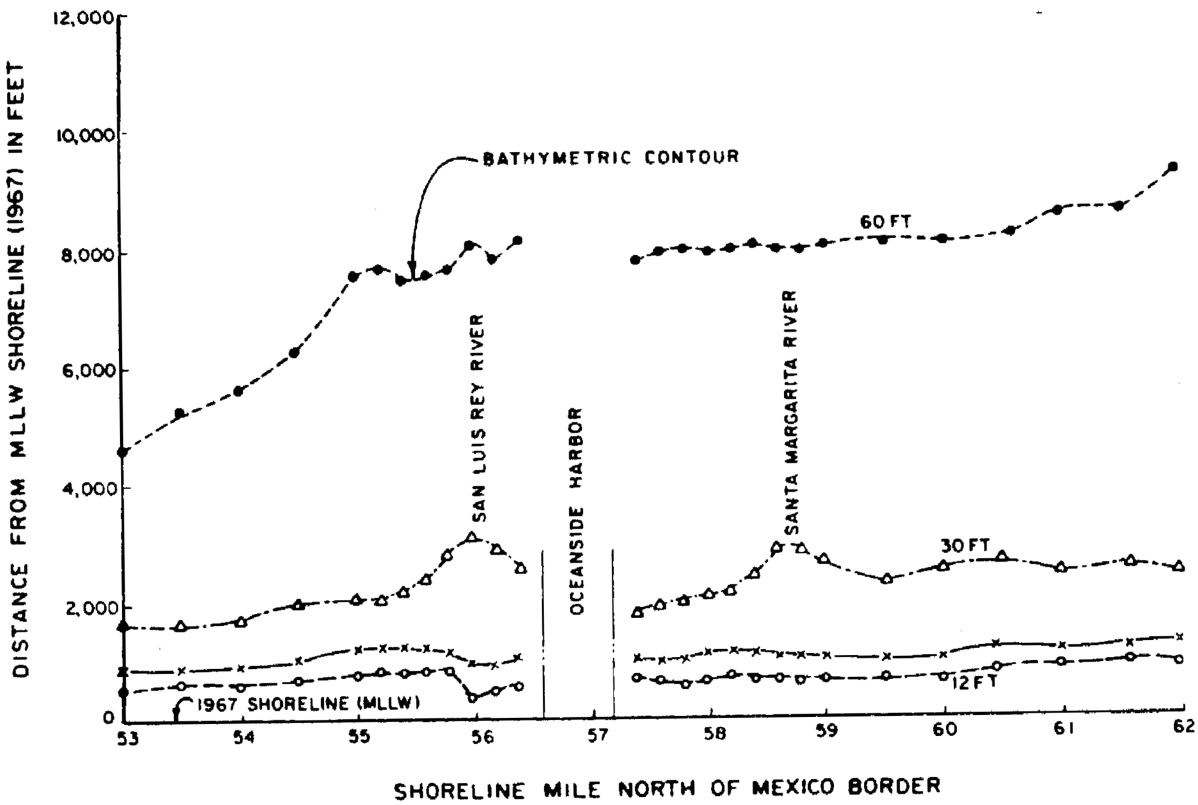

Figure 11. Bathymetry near Oceanside from 1934-35 USC and GS hydrographic surveys.

discharge in the San Luis Rey River occurred in 1916. Maximum flow in the Santa Margarita River was in 1927.

The impoundment and sediment storage characteristics of the lower reaches of the rivers is the second way in which the two rivers differ. Sediment moving down the Santa Margarita River must pass through a relatively large coastal lagoon before reaching the littoral zone. This means most of the sand moving in the Santa Margarita River reaches the coast only during exceptionally high flow events. At lower flows sand is deposited in the downstream, low-gradient reaches of the river channel and in its coastal lagoon as flow velocity decreases with decreasing energy slope and with increasing lagoon cross-sectional area. The floodplain of the San Luis Rey River is narrow near the ocean and does not function as a low-flow sand trap. Coarse sediment thus reaches the coast in the San Luis Rey River at much lower flows and more frequently than it does in the Santa Margarita River.

The drainage basin of the Santa Margarita River is 750 mi^2 area, of which 26 percent is agricultural and 5 percent is urbanized (Brownlie and Taylor, 1981). Three storage facilities, O'Neill Lake completed in 1883, Vail Lake completed in 1949, and Skinner Lake completed in 1973, control 380 mi^2 of the drainage basin. Vail Lake controls 84 percent of that area. Brownlie and Taylor (1981) estimate an average 1.4×10^4 tonnes of sand and gravel were carried to the upstream end of the Santa Margarita River lagoon in the period 1931 to 1975 with 1.8×10^5 tonnes delivered in the 1969 water year (1yd^3 is equal to about 1.3 tonnes). Under natural conditions they estimate the discharge would have been 1.2 times the 1939 to 1975 estimate.

The San Luis Rey River drainage basin covers an area of 560 mi^2, of which 30 percent is devoted to agriculture and 6 percent is urban. Lake Henshaw is the only major storage facility. Constructed in 1922, it controls 37 percent of the total drainage area. Brownlie and Taylor (1981) estimate the average annual sand and gravel discharge to the ocean at 2.2 x 10^4 tonnes between 1930 and 1975. They estimate the annual sand and gravel discharge under natural conditions to have been 6.7 x 10^4 tonnes/yr or about 3 times as great as the present discharge. In the 1938 water year they estimate 3.6 x 10^5 tonnes were carried to the coast.

A characteristic of the climate in southern California is alternating, non-uniform length, wet and dry cycles. Wet periods are often also times when wave storms are more severe and frequent. Several especially wet periods are notable examples. The first is the period from 1884 to 1891 when severe cyclones affected the coast in 1884, 1886, 1889, 1890 and 1891 (Kuhn and Shepard, 1984). The second is the recent 1978-1983 wet period. In the 20th Century, the periods 1903-1911, 1914-1918 and 1935-1941 were also abnormally wet. The twenty-plus year period before 1978 has generally been considered very dry. The interval from 1842 to 1883, with the exception of 1861-1862, was also very dry (Lynch, 1931).

Exceptional floods contribute the largest quantity of sediment to the coast. Discharge during these events can be several orders of magnitude larger than the average annual sediment input from rivers. Evidence from piston cores of inner-Continental margin basins suggests large floods occur at a frequency of once per few centuries (Malouta et al. 1981; Thornton, 1981; Gorsline et al. 1984) and dominate the sediment record.

(2) Longshore Sediment Transport Rates. Dredging at Oceanside Harbor between 1963 and 1979 was at an annual rate of 2.9 x 10^5 yd^3 (Weggel

and Clark, 1983). This rate is probably greater than the net longshore sediment transport rate north of the harbor, but less than the gross rate at the harbor. The Corps of Engineers (1980) estimates the potential net longshore sediment transport rate at Oceanside to be 1 x 10^5 yd^3/yr - south, and the gross rate at 11.8 x 10^5 yd^3/yr.

A local factor probably contributes to a longshore sediment transport gradient south of Oceanside Harbor. Carlsbad Submarine Canyon located south of Oceanside, and especially the progressive narrowing of the inner-Continental Shelf beyond a depth of 30 ft south of the Oceanside Pier (Fig. 11), tends to create an alongshore variation in the wave approach direction that probably reduces longshore transport to the south. There is no corresponding bathymetric control north of Oceanside. Assuming deepwater wave characteristics north and south of Oceanside are similar, the effect of the bathymetric controls along the coast south of the harbor is to somewhat enhance transport to the north and reduce it to the south. Corps of Engineers (1980) refraction diagramps support this hypothesis. The magnitude of the alongshore gradient south of the harbor is unknown. The transport potential in an alongshore direction north of the harbor is nearly constant. Island blocking and the effects of refraction adjacent to offshore islands may also impose an alongshore gradient on the net longshore sediment transport rate in the Oceanside area.

(3) Seacliffs. The seacliff line shown on Figure 12, oriented at 324 degrees, is remarkably straight. When projected across the floodplains of the San Luis Rey and Santa Margarita Rivers the seacliff does not vary by more than 150 ft from a remarkably straight line, 10-mi long. To a point about 2-mi south of the harbor the present seacliff line is landward of all surveyed

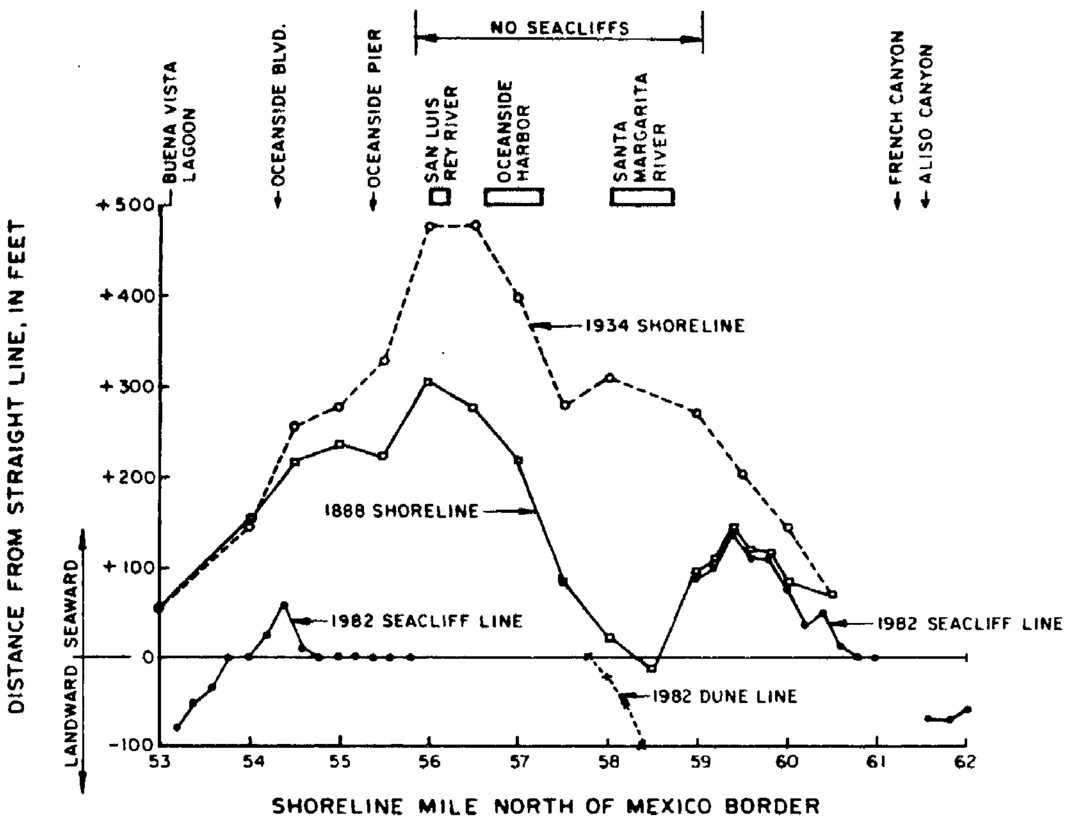

Figure 12. Shorelines at Oceanside before the harbor was constructed; note the remarkably straight seacliff line on either side of the San Luis Rey and Santa Margarita Rivers; distance between shorelines and seacliff line (solid circles) is approximately equal to beach width.

shorelines (Figs. 12 and 13). The linear, shore-parallel trend of the seacliff line in this reach, however, suggests it was scoured by waves and the toe of the seacliff was coincident with the shoreline sometime before 1888, quite possibly during the very dry period between 1842 and 1884 (Lynch 1931). The only major flood that contributed sand to the coast in that period was in 1861 and 1862. During the 20-yr long periods before and after the 1861-1862 floods, sand was carried away from deltas at the river outlets by marine processes. The shoreline in 1888, at the time of the earliest survey, was at its historic retreat position (Figs. 12 and 13). Yet 1888 was just 4 years after one of the heaviest floods in recorded time (Lynch, 1931). This suggests the pre-1884 shoreline might have been located at a more landward position than the 1888 shoreline, and that the seacliffs may have been attacked by waves at Oceanside in the 1862 to 1883 period not too long before development occurred.

The seacliff north of the Santa Margarita River entrance (Mile 58.8 to Mile 59.8) was scoured by waves in the 1888 period as shown in Figure 12. The seacliff line and the shoreline were coincident in 1888. Since 1888 a widening beach has protected those seacliffs, especially in recent times when the shoreline advanced north of the harbor (Fig. 13). A reduction in sand supply before 1888 probably resulted in the indentation of the 1888 shoreline at the Santa Margarita River mouth (Fig. 12). This suggests sediment carried by the river in the floods of 1884 was deposited in the lagoon. From 1888 to 1933, however, there were a number of major floods (1891, 1916 and 1927, plus moderate floods in 1889, 1895, 1906 and 1921) that transported sand and deposited it off both river entrances, especially widening the beach off the Santa Margarita River (Fig. 12). River discharge exceeded the capacity of longshore sediment transport processes to carry the sand away in this period.

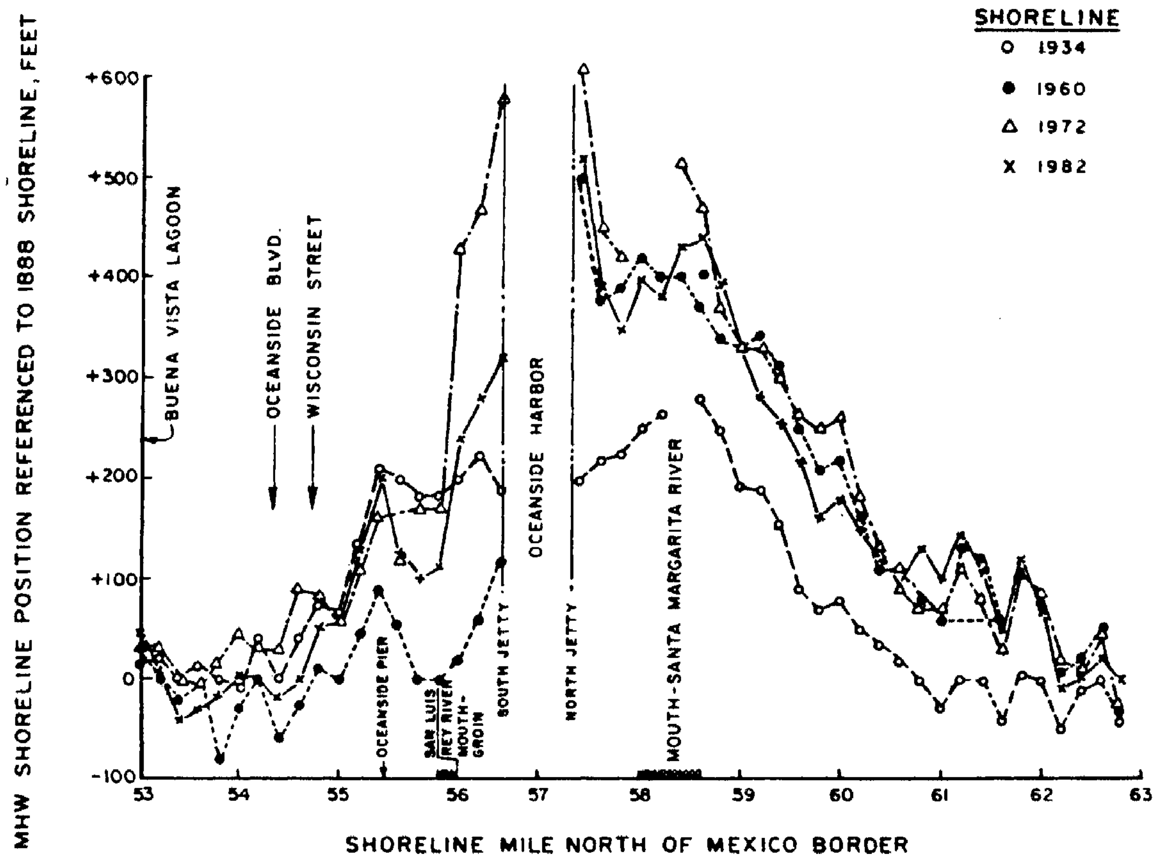

Figure 13. Shorelines before and after Oceanside Harbor was constructed; the zero reference shoreline of 1888 was generally landward of all subsequent shorelines; see Figure 12 for 1888 shoreline position with respect to seacliff line.

(4) Shoreline Changes. Surveyed MHW shorelines varied within a 60 ft envelope south of Oceanside Blvd (Mile 53.5) and north of Mile 62.5 at Camp Pendleton. In the 9-mi long intervening reach the shoreline varied from survey to survey by as much as 300 ft, and by over 500 ft between 1888 and 1982. Away from the river entrances seacliffs behind the beach were attacked by waves after 1888. At north Oceanside the seacliffs have been protected by a wide beach since 1888. Development has occurred on this beach in the past 80 years.

In 1888 the widest beach (greatest distance between the seacliff and the shoreline) was near the mouth of the San Luis Rey river (Fig. 12). Since then there has been a general shoreline movement away from the seacliff both north and south of the river entrances as shown on Figure 13. An exception is the 1960 shoreline south of the San Luis Rey River (Fig. 13). Shoreline retreat in the pre-1960 period apparently occurred because of reduced sand bypassing around the harbor as the north fillet was expanding (Fig. 13) at a rate of about $2 \times 10^5 yd^3/yr$. Sediment discharge in the rivers was low between 1940 and 1945 and negligible from 1945 through 1960 (Brownlie and Taylor, 1981).

The north jetty at Camp Pendleton, constructed in 1942, appears to have stabilized the shoreline north of the harbor. Its effect by advancing the shoreline was greater than the effect of floods in the Santa Margarita River. As shown in Figure 13, the north jetty was responsible for creating a shoreline that attained a stable configuration before 1960. Since 1960 the shoreline north of the harbor has been relatively stable. Sediment is no longer being deposited in significant quantities updrift of the harbor. Fluctuations between 1960 and 1982 were generally ± 30 ft of the mean shoreline position. This is within the practical uncertainty limits of the NOS shorelines. The only change from the nearly stable position north of the harbor was a 100 ft advance in the 1972 shoreline at the Santa Margarita River entrance. That advance, which slowly decayed to 1982, was probably caused by sediment transported to the coast in the flood of 1969.

The fillet that was created by the north jetty advanced the shoreline about 110 ft and extended it 5.5 mi upcoast of the harbor (Fig. 13), or about 2 mi further north than the river delta shoreline projected seaward in 1888 and 1934 (Fig. 12). The fillet shoreline varies from the regional orientation of the shoreline by less than 2 percent. North of the fillet the shoreline sweepzone from 1888 through 1982 was less than 60 ft.

Sediment deposited updrift of the north jetty after the harbor was constructed must have come as a result of longshore sediment transport from the north. Very little sediment, if any, was delivered to the coast by the Santa Margarita River between 1942 and 1960. Corps of Engineers (1980) bathymetric surveys indicate the shoreface north of the fillet out to about -30 ft remained stable from 1934 to 1972. While the shoreline in the fillet area advanced, bathymetric contours retreated somewhat, i.e., the shoreface steepened in the fillet area. The reason for this steepening is not clear. However, one guess is that the 1934 bathymetric contours had previously been advanced by the formation of a delta in the 1927 flood, and since then they retreated. If this is the case the harbor was not responsible for the retreat.

Offshore Oceanside Harbor sediment has been deposited. Corps of Engineers (1980) surveys show all bathymetric contours out to and including the -30 ft contour moved seaward between 1934 and 1972, i.e., a submerged delta formed.

Sand bypassing has not increased the sand volume on beaches south of Oceanside Harbor. Even with almost 12 x 10^6 yd^3 of new material and bypassed sediment (Table 12 and Fig. 14) placed at Oceanside between 1942 and 1979, the shoreline south of the harbor did not advance except as shown by the 1972 survey. This advance was probably enhanced by sediment contributed in the 1969 flood in the San Luis Rey River and the 4 x 10^6 yd^3 of material excavated from the harbor and placed on the beach in the early 1960's (Table 12). The average nourishment rate at Oceanside from 1942 to 1979 was 3.3 x 10^5 yd^3/yr of material from harbor excavation and material dredged from the entrance channel. Maintenance dredging at Oceanside Harbor has supplied only about 60 percent of the quantity placed on the beaches. Sand from new work dredging and sand brought in from outside sources, including the San Luis Rey River, has been required.

Since San Luis Rey River discharge (average about 2 x 10^4 yd^3/yr) is not included in the 3.3 x 10^5 yd^3/yr nourishment rate, it appears over 3.5 x 10^5 yd^3/yr are required to maintain the 3-mi long Oceanside beach from Mile 53 to Mile 56 in nearly the same position it was in 1888 and 1934. Indeed, Corps of Engineers (1980) survey evidence indicates the shoreface has been steepening south of the harbor, so that the 3.5 x 10^5 yd^3/yr reaching the beaches was not enough to maintain pre-1934 conditions. Before 1934, Oceanside beach was maintained by longshore sediment transport with a net southerly direction, and by relatively infrequent, but large, discharges of sand from the rivers.

Sediment losses at Oceanside beaches today appear to be occurring because of a disruption in the net volume of sand supplied from upcoast (north) regions, a net loss of sand caused by alongshore transport to the north and deposition at and offshore the harbor, and a reduction in the volume of sand delivered by

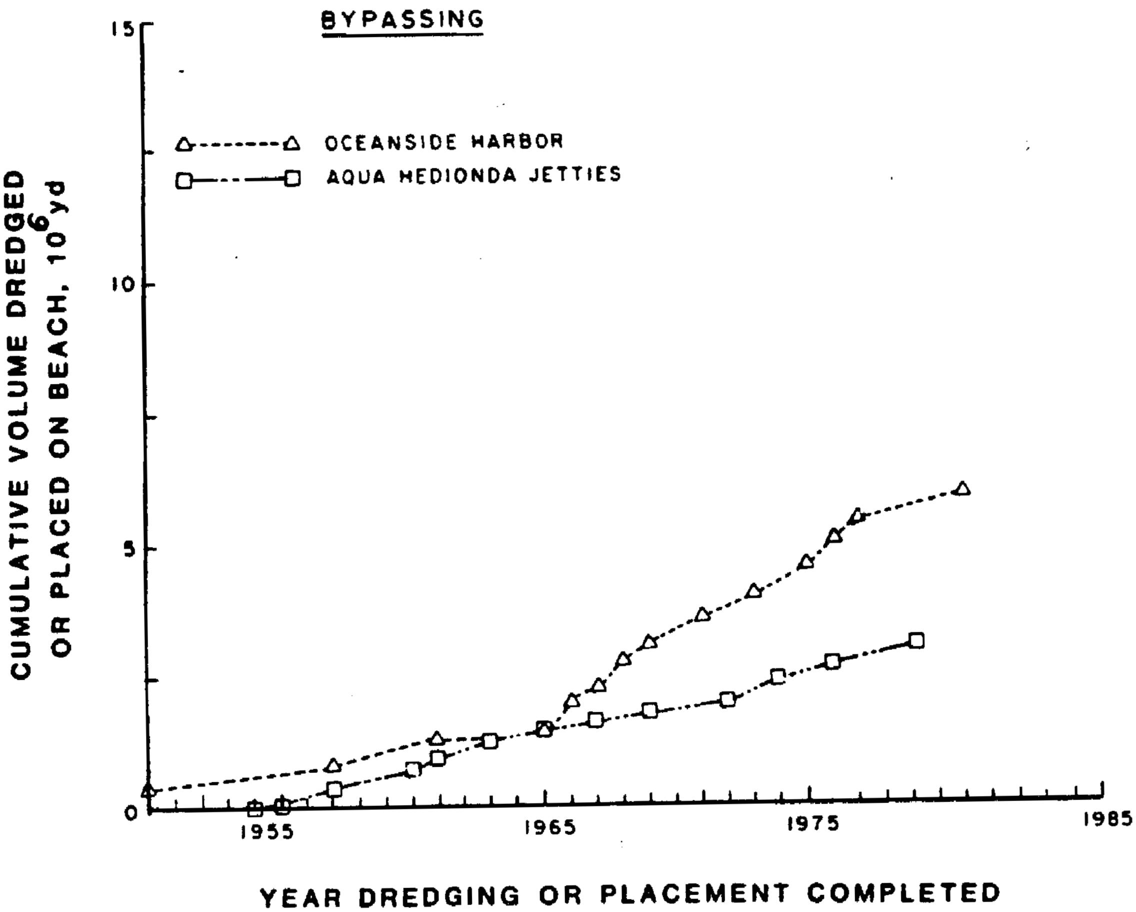

Figure 14. Sediment volume dredged from Oceanside Harbor and Aqua Hedionda Lagoon in recent years (from Shaw, 1980).

the rivers. The average sand discharge by both rivers, estimated to be about 3×10^4 yd^3/yr by Brownlie and Taylor, (1981), was much less than the present day beach sand loss at Oceanside of over 3.5×10^5 yd^3/yr.

Littoral sediment presently appears to be moving in both directions toward the harbor. Until sometime before 1960 when the north fillet stabilized, the net accretion rate updrift of the north jetty was about 2×10^5 yd^3/yr (using Eq.1 and considering shoreface steepening). The $2 \times 10^5 yd^3/yr$ includes the net longshore sediment transport rate and the volume of sediment discharged by the Santa Margarita River. After 1960 the 2×10^5 yd^3/yr moved to the harbor. South of the harbor during the same period the beach and shoreface slowly deteriorated even though about 3.5×10^5 yd^3 per year was artificially and naturally (river discharge) added. The volume lost south of the harbor appears to be 1.5 to $2.5 \times 10^5 yd^3/yr$ larger than the net longshore transport rate north of the harbor. The net longshore sediment transport rate south of the harbor may be near the 1.25×10^5 yd^3/yr deposited in Aqua Hedionda Lagoon, which is consistant with the hypothesis there is a longshore sediment transport gradient south of the harbor.

About 2×10^5 yd^3/yr of the loss south of the harbor is probably not the result of longshore transport to the south. Corps of Engineers (1980) surveys suggest it is not moving offshore of Oceanside. It must therefore be moving in a northward direction toward the harbor and lost there. Coupled with the approximately 1.5 to 2×10^5 yd^3/yr moving to the harbor from the north, perhaps 4×10^5 yd^3/yr is reaching the harbor from both longshore directions. About 3×10^5 yd^3/yr of that is being dredged and placed on the Oceanside beach. The difference of 1×10^5 yd^3/yr is apparently carried seaward and deposited offshore the harbor.

(5) Summary. NOS shoreline maps can be used to evaluate shoreline behavior at Oceanside over a period of about 100 years. The maps show the 1888 shoreline was landward of all subsequent map shorelines (1934, 1960, 1972, and 1982) north of Oceanside Pier. In 1960, the shoreline to 2-mi south of the pier was up to 80 ft landward of the 1888 shoreline. In 1888 beach width averaged 100 to 200-ft in this reach. Starting at the time the north jetty of Oceanside Harbor was constructed in 1942 and ending before 1960, the shoreline north of the harbor advanced about 110 ft over a 5.5-mi distance. The advance created a fillet that was 500-ft seaward of the 1888 shoreline near the jetty and 50-ft seaward of the seacliff at Camp Pendleton. In 1888 the shoreline was at that seacliff. Since 1960 the shoreline north of the harbor has been stable (within uncertainty limits of ±30 ft).

Since before 1888, when the first local shoreline survey was made, until 1942, when harbor construction began, the primary control on shoreline behavior near Oceanside was sediment availability. To the present sediment availability plays an important role. Sporadic sediment discharge by the San Luis Rey and Santa Margarita Rivers caused rapid shoreline advances and created deltas. Significant retreats occurred during dry, low sediment-discharge periods when longshore transport processes slowly removed the delta deposits. Sometime, probably between 1842 and 1883, the seacliffs along the length of the Oceanside shore were cut by waves during a low discharge period.

Jetties constructed at Camp Pendleton Harbor in 1942, and expanded when Oceanside Harbor was constructed in the early 1960's, modified the local longshore and cross-shore sediment transport regime. Shoreline behavior was markedly changed. Cycles of large shoreline advances and retreats were replaced by a steady advance until about 1960 north of the harbor, by a loss south of the harbor that was mitigated by artificially adding sand, and by deposition seaward of the harbor structures. A simple sediment budget analysis indicates about 1 x $10^5 yd^3/yr$ have been lost offshore the harbor since about 1960.

h. Camp Pendleton Subreach (Mile 62.8 to 73.0). This mostly undeveloped reach is backed by seacliffs composed of partly consolidated sediments. Seacliff elevations range from 80 to 140 ft. San Onofre Nuclear Generating Station, constructed in the mid-1970's is located at Mile 71.2 (Fig. 15). The shoreline on either side of the seawall at the power station has advanced with the largest seaward movement (about 150 ft between 1972 and 1982) northwest of the station. The advance southeast of the plant was about 60 ft in the same period.

Map shoreline changes between 1888 and 1982 are mostly contained within a 100-ft envelope (slightly larger than the practical bounds of uncertainty, but smaller than the maximum uncertainty limits). As shown in Table 13, the shoreline advanced an average of about 60 ft between the time of the 1889 survey and the 1982 survey or about 0.7 ft/yr. The only period of retreat was between the surveys of 1960 and 1972. The largest advance occurred between 1934 and 1960. Interestingly, between 1889 and 1934 the northern part of the reach advanced and the southern part retreated, while from 1934 to 1960 the largest advance occurred in the south while in the north only a small average advance is indicated. These trends are just the opposite of the alongshore shifts shown in Figures 6 and 7 that occurred in the Silver Strand Littoral Cell in those periods.

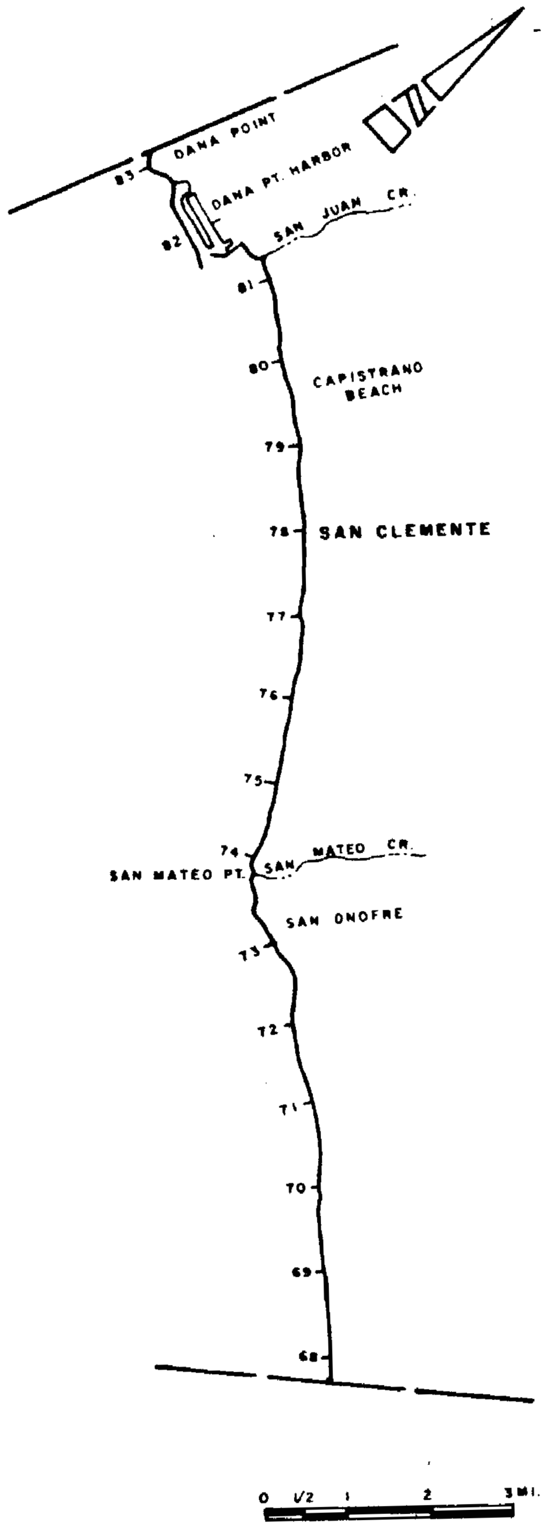

Figure 15. Location map, north one-third of Oceanside Littoral Cell.

TABLE 13. Shoreline Change Rates, Camp Pendleton

SHORELINE INTERVAL (Mile)	SHORELINE SURVEY RATES[1] 1889-1934	1934-1960	1960-1972	1972 1980
63-64	-0.7	+2.0	+0.2	-1.8
64-65	-0.1	+2.6	+0.3	-1.2
65-66	-0.0	+2.9	-3.9	+5.3
66-67	-0.5	+1.8	-2.7	+5.1
67-68	+0.7	+1.6	-2.1	-0.7
68-69	+0.4	+1.4	-0.9	+1.8
69-70	+1.9	-0.5	+0.1	+3.5
70-71	+1.2	+0.3	-1.4	+5.6
71-72	+0.9	+0.4	-1.0	+9.1
72-73	-1.7	+0.4	+7.5	-1.3
average	+0.2	+1.3	-0.4	+2.5
average shoreline change	+9 ft	+34 ft	-5 ft	+25 ft

[1] in feet per year, averaged by shoreline interval, and averaged between survey dates

The floodplain of Los Flores Creek entrance widens to 0.6 mi within one-third mile of the coast. There is no true lagoon, however, and the creek discharges about midpoint between the low bluffs that bound the outlet. Since 1888 the outlet has remained in that vicinity, migrating over only about 20 percent of the outlet floodplan. The outlet was open in 1888 and 1982. Shoreline changes at the outlet of Las Flores Creek were within a map envelope of 80 ft between 1888 and 1982.

i. San Mateo Creek Subreach (Mile 73.0 to Mile 73.8). This creek outlet is located at the southeast side of San Mateo Point where the orientation of the shoreline changes about 60 degrees. San Mateo Creek discharges near the northwest side of its 0.8-mile wide floodplain. Between 1888 and 1982 the shoreline moved in an envelop of less than 100 ft. In 1888 the outlet was against the bluffs at the north side of the sweep zone. A 1,000-ft long and 100-ft wide spit extended north from the southerly location of subsequent entrances suggesting: (1) the most frequent location of the entrance is usually about 1,000 ft southeast of the bluffs, and (2) longshore sediment transport prior to the 1888 survey may have been to the north.

j. San Clemente Subreach (Mile 73.8 to Mile 81.0). This shoreline is backed by the Atchison, Topeka and Santa Fe Railroad right-of-way on the seaward side of the seacliff. Houses and Highway 101 (El Camino Real) have also been constructed seaward of the seacliffs from Mile 77.7 to Mile 81.0. Shoreline map data are available for the years 1934, 1960, 1972 and 1982 (Table 14).

TABLE 14. Shoreline Change Rates, San Clemente Subreach

SHORELINE	SHORELINE SURVEY DATES[1]			
INTERVAL (Mile)	1934-1972	1934-1960	1960-1972	1972-1982
74.0-75.0	+1.2	+3.4	-3.6	-0.6
75.0-76.0	-1.1	+1.2	-6.0	+2.0
76.0-77.0	-1.2			+9.2
77.0-78.0	-1.4			+1.3
78.0-79.0	-1.8			+4.7
79.0-80.0	-1.4	-0.2	-4.1	+11.1
80.0-81.0	+0.1	-1.6	+3.9	+12.9

[1]in feet per year averaged by shoreline interval, and averaged between survey dates

Shoreline movements as depicted on the maps were generally within the maximum uncertainty bounds (Fig. 4) except near the north end of the reach where the shoreline had advanced significantly since 1972. In the late 1960's about 900,000 yd^3 of sand from a land source was placed on the beach in the Mile 79-81 reach.

Figure 4 shows the retreat that occurred in the mid-portion of the San Clemente subreach between 1934 and 1972. The shoreline advanced from 1972 to 1982 with the greatest advance southeast of the San Juan Creek outlet and at the San Clemente Pier. San Juan Creek is a source of littoral sand. Shoreline changes between 1967 and 1981, obtained from aerial photographs (Orange County, 1985) show the large shoreline advance between Mile 78.5 and 81.0. This advance occurred because of the sheltering effect of the south breakwater of Dana Point Harbor which was completed in 1968. The breakwater reduces the amount of wave energy reaching that shore and hence reduces the net, south-directed longshore sediment transport rate. Sediment carried to the coast in San Juan Creek is not removed and carried downcoast as rapidly as it was before the harbor was constructed. The shoreline retreat that occurred in the 1967-1981 period between Mile 77.0 and 78.5 (Fig. 4) is consistant with the shoreline retreat trend at that location from 1934 to 1972.

k. Unstructured Lagoon Outlets, San Diego County South of Oceanside. Many relatively small streams discharge into coastal lagoons in San Diego County. When the ocean outlets remain open wetland growth is enhanced by saltwater circulation. When the volume of littoral sediment moved to an outlet by longshore transport processes exceeds the volume transported away by tidal currents the outlet becomes constricted and may close. Marine organisms that must transit the outlet are then either trapped in the lagoon or prevented from entering it. Water quality in the lagoon also changes, usually to the detriment of wetlands biota. In the absence of fresh water runoff the closed lagoon becomes hypersaline as a result of evaporation. Significant freshwater runoff, however, dilutes the salt content. Lagoons without an ocean outlet are thus likely to experience wide fluctuations in salinity.

Shoreline maps provide limited information on outlet geometry and opening/closure characteristics at the time shoreline surveys were made. This information may assist in better understanding the wetlands resource and the stability of fronting beaches. Lagoons considered in this shoreline analysis are listed at Table 15.

TABLE 15. Coastal Lagoons Considered in San Diego County

Lagoon	Shoreline Mile
Tijuana River Estuary	1.7
Los Penasquitos	35.9
San Dieguito River	38.9
San Elijo	41.7
Batiquitos	46.9
Aqua Hedionda	51.1
Buena Vista	52.9

(1) Tijuana River Estuary (Mile 0 to Mile 2.1). This 2 mi^2 estuary is mostly subaerial at MHW. Based on a 1937 to 1975 period of record Brownlie and Taylor (1981) estimated the sediment discharge rate in the Tijuana River at 2.5×10^5 yd^3/yr before three dams were constructed, and at 1.2×10^5

yd^3/yr in its present modified condition (1 yd^3 is assumed equal to 1.3 tonnes).

Outlet behavior appears to reflect changing water and sediment discharge conditions. The outlet, between the time the five shoreline surveys were made, narrowed and migrated to the north (Fig. 16). Northward migration has been about 10 ft/yr. Outlet migration parallels sediment adjustments in the littoral cell as shown in Figure 7. In the 1972-1982 period when littoral sand moved in a south-to-north direction, as well as offshore, the entrance moved north. The opposite occurred in the 1960-1972 period when the south end of the cell gained sand.

Entrance width is sensitive to longshore sediment transport rates and the tidal range that existed just before the shoreline survey was made. Nevertheless, the trend to a narrower entrance is reasonable because of reduced scour capacity resulting from reduced freshwater discharge in recent years.

Several arguments suggest the estuary has not significantly filled since 1851. Almost 14 x 10^6 yd^3 of sand and gravel was probably discharged to the upper Tijuana River estuary between 1884 and 1944 (Moffatt and Nichol, Engineers, 1987). If deposited in the estuary, that sand and gravel would have increased the estuary level by 7 ft. This clearly did not occur. Most of the sediment must have been carried through the estuary to the coast. Low flood flows, perhaps those below 10,000 cfs, may carry sand and gravel to but not through the Tijuana River Estuary. However, infrequent, but larger floods, carry most of the previously deposited and stored material, as well as the sand and gravel moved downstream by the larger flood, through the estuary to the ocean.

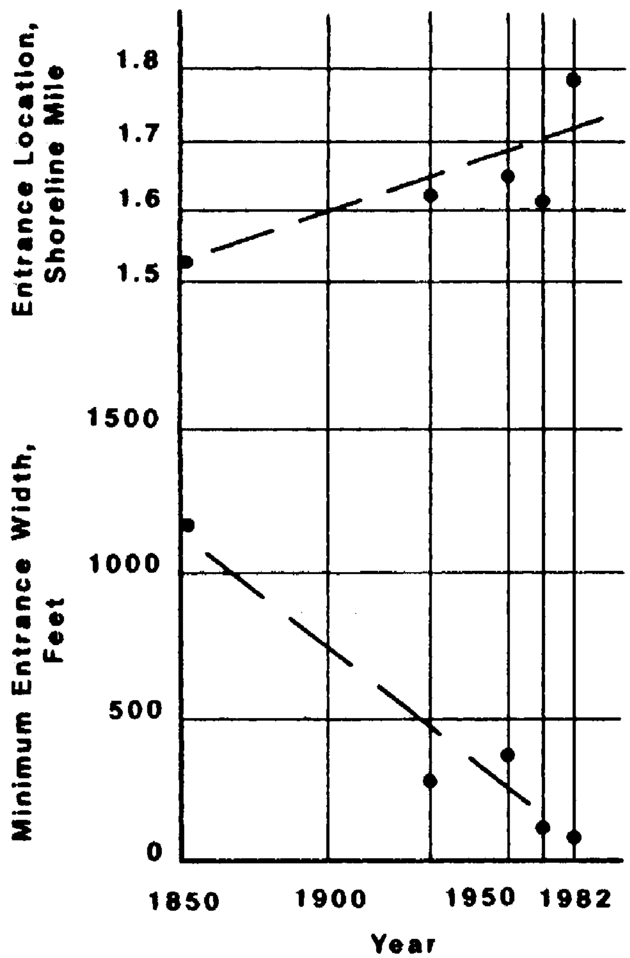

Figure 16. Changes in the entrance of the Tijuana River between 1851 and 1982.

Oneonta Slough, a north-trending arm of the estuary, has not filled to any great extent in recent times as indicated on the shoreline maps. This suggests sediment delivered to the landward reaches of the estuary is carried directly west through the estuary to the coast during major floods. The occurrence of a significant backwater effect and ponding in the estuary apparently is minimal during major floods.

(2) Los Penasquitos Creek (Mile 35.5 to Mile 36.3). The shoreline at this creek outlet has fluctuated within the uncertainty bounds of the maps. In 1888, a year of extraordinary rainfall, the outlet of Los Penasquitos Creek was open and about 1500 ft north of its present location (Fig. 17). The outlet was also open in 1982, but closed in 1933, 1960 and 1972 when other shoreline surveys were made. In historic time the outlet has been within the northern one-half of lower Soledad Valley. Presently the outlet location is fixed by a bridge over the Pacific Coast Highway.

(3) San Dieguito River (Mile 38.8). This river outlet is at the north boundary of its floodplain. In 1888 the river shoreline was against the bluffs a few hundred feet inside the protective seacliff. Floods in the 1880's may have been responsible for cutting the bluff. In 1888 and 1982 the outlet was open; in 1933, 1960 and 1972 it was closed (Fig. 17). No evidence of a delta deposit is evident off the San Dieguito River.

(4) San Elijo Lagoon (Mile 40.6-41.7). The outlet of this lagoon has been at the extreme north side of its floodplan in historic times (1888 to present). About 70 percent of the lagoon is presently open water (Fig. 17). The 1933 shoreline represents the maximum retreat location, but shoreline

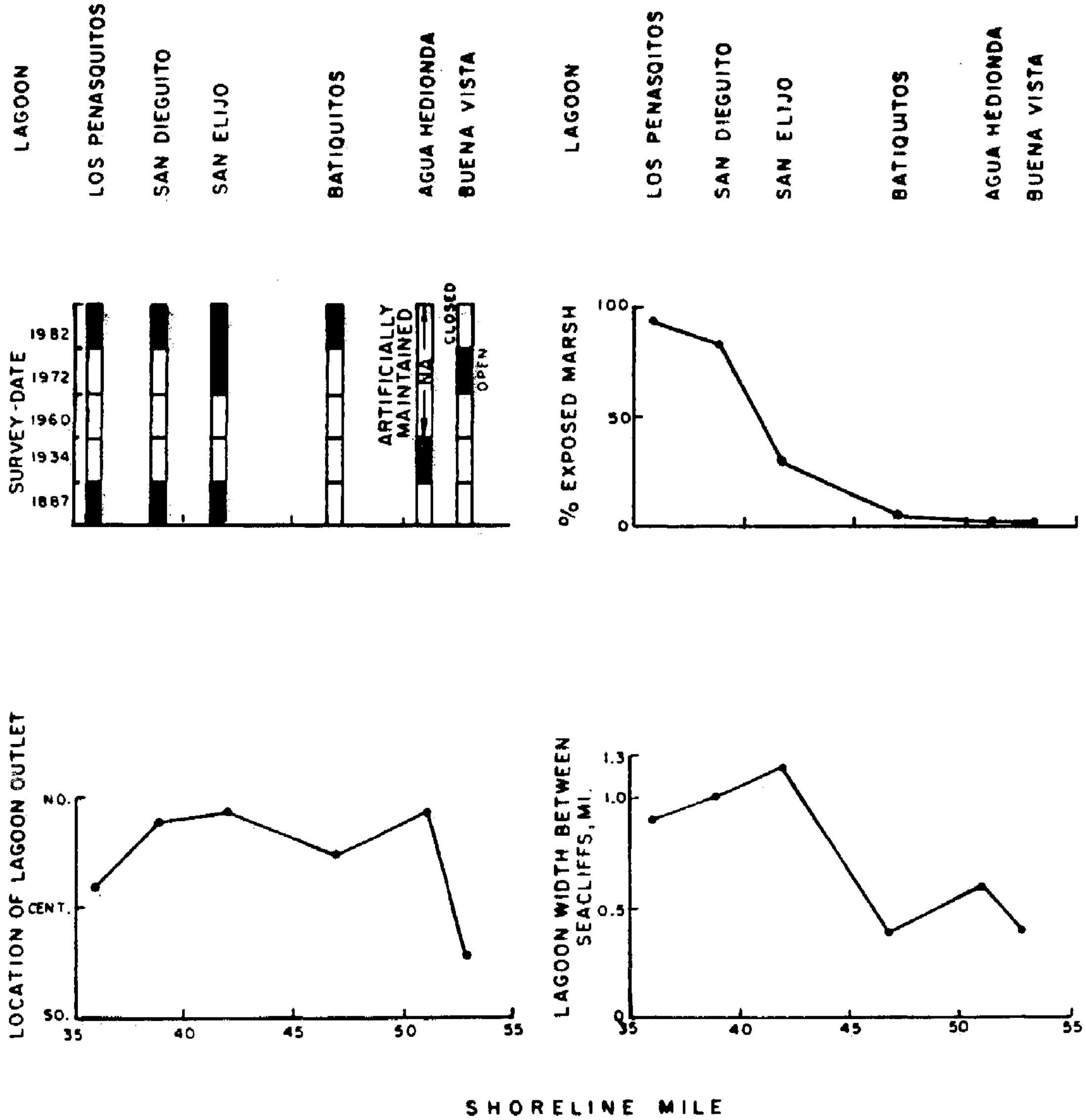

Figure 17. Characteristics of lagoon entrances south of Oceanside, San Diego County, California.

changes on the spit that separates the ocean and lagoon have generally advanced since 1888 (maximum 130 ft at Mile 40.7). The lagoon outlet was open in 1888, 1933 and 1982, and closed in 1960 and 1972.

(5) Batiquitos Lagoon (Mile 46.7-47.0). Batiquitos Lagoon is almost all open water (Fig. 17). A comparison of the 1933 and 1983 shorelines of the lagoon indicate the open water area increased slightly in that period. The ocean entrance of this lagoon was only open at the time the 1982 shoreline was established. The outlet was located at the north side of the lagoon from 1888 to 1982. Between 1888 and 1972 the ocean shoreline of this 0.3-mi long reach advanced about 150 ft or an average 2 ft/yr. This advance is greater than that which appears to have occurred on nearby beaches. From 1972 to 1982 the shoreline retreated an average 70 ft.

(6) Agua Hedionda Lagoon (Mile 50.8-51.4). This lagoon is controlled on both the north and south ends by double, shore-normal structures. Two 500-foot long jetties at the north end were designed to stabilize and maintain an inlet, the purpose of which is to provide an uninterrupted flow of salt water to power plant intakes in the lagoon. Two 400-foot long jetties at the south end were designed to provide a discharge outlet for the powerplant. All jetties were constructed in 1954. The lagoon was naturally open at the north end in 1934. In 1888 it was closed. The width of the barrier separating ocean and lagoon at both the north and south ends was less than 100 ft in 1888. Natural channels approached the coast at both ends of this open lagoon.

The 0.6-mi long reach that separates the lagoon from the ocean is a barrier spit. Before 1954 it was maintained by littoral sediment transported parallel to shore. Since construction of the jetties, the barrier has been artificially maintained. In 1954 the outer (western) lagoon was initially dredged and 4 x 10^6 yd^3 were placed north of the north jetties and between the north and south jetties. The between-jetty beach was initially widened 400 feet. Figure 18 shows the volume dredged from the lagoon between 1954 and 1979 (from Shaw, 1980) and placed either entirely between the sets of jetties, or partially between the sets of jetties and partially north of the north jetty. Shoreline location in 1934 averaged about 190 ft landward of the 1960 map location (Table 16). The 1972 shoreline averaged about 110 ft landward of the 1960 shoreline.

TABLE 16. Shoreline Change Rates, Vicinity of Aqua Hedionda Lagoon, 1888-1982.

SHORELINE	SHORELINE SURVEY RATES[1]			
INTERVAL (Mile)	1888-1934	1934-1960	1960-1972	1972-1982
50.0-50.8	-0.1	+3.0	-5.0	+12.6
50.8-51.4[2]	-0.4	+7.2	-6.7	+5.3
51.4-52.0	-0.7	+2.2	+1.1	-1.2

[1]in feet per year averaged by shoreline interval and averaged between survey dates

[2]north entrance to Agua Hedionda Lagoon is at Mile 51.4; the south cooling water outlet is at Mile 50.8

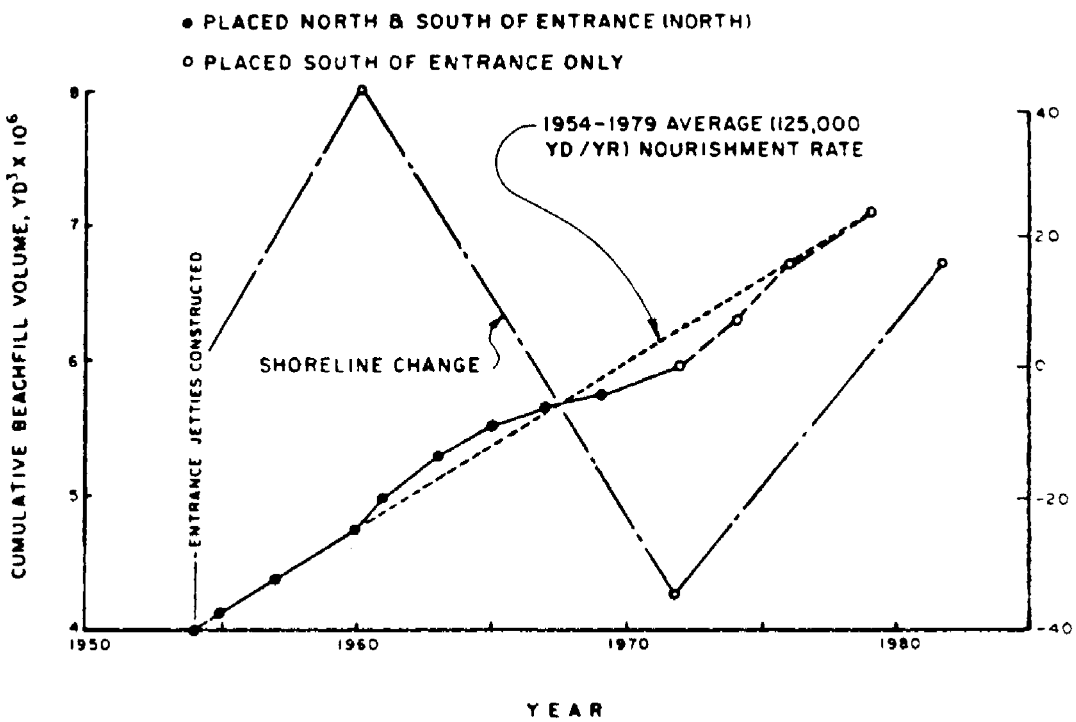

Figure 18. Shoreline changes and cumulative beach nourishment volume at Agua Hedionda Lagoon (modified) from Shaw, 1980).

Shoreline position appears closely related to the quantity of fill material placed on the barrier beach. Between 1954 and 1979 the shoreline was maintained by the addition of an average 1.25×10^5 yd^3/year of material dredged from the lagoon (Fig. 18). When the average $1.25 \times 10^5 yd^3$/yr nourishment rate was reduced in the mid to late 1960's the shoreline retreated. In 1972, the cumulative volume of placed beachfill was about 2.5×10^5 yd^3 below the 25 year average as a result of the reduced 1965-1971 placement rate. After 1972 the dredging rate increased and the shoreline advanced. Sand dredged from the lagoon came from the littoral zone through the inlet stabilized by the short north jetties. Dredging at Agua Hedionda Lagoon is a form of sand bypassing.

(7) Buena Vista Lagoon (Mile 52.8-53.1). The five map shorelines that are available at the mouth of this lagoon show a change of $\pm$ 40 ft since 1888. Of note is the location of the lagoon entrance. It is at the southern one-forth of the barrier beach (Fig. 17). The channel was only open in 1972. The entrance position has been stable in the past 100 years.

(8) Summary - Lagoon Outlets. The character of lagoons and lagoon outlets between La Jolla and Oceanside tend to vary with some consistency in an alongshore direction. Most noticeable of the alongshore trends is that of percent exposed marsh. As shown in Figure 17, the lagoons in the south are filled with sediment. In the north the lagoons are open.

Interestingly, the outlets of lagoons in the south were open at the time surveys were made more often than the lagoons in the north (Fig. 17). While the number of times is not too important, the relative difference in an alongshore direction suggests the outlets of the southern lagoons might be open more often than those further north, possibly because longshore transport rates are greater in the north or the availability of sediment is greater in the north. San Elijo Lagoon was open 60 percent of the time surveys were made. Batiquitos and Buena Vista (a small lagoon) Lagoons were open at the time of only 20 percent of the surveys.

When open, the lagoon outlets have been located toward the north side of their floodplains (Figure 17). The only exception is the outlet of Buena Vista lagoon. The outlet location on the north side of the lagoons is somewhat contrary to the belief that net south longshore transport will tend to force the outlets to the south. Lagoon width between the bluffs decreases to the north as shown in Figure 17.

4. <u>Laguna Beach Littoral Compartment</u>. This reach extends from Dana Point (Mile 83.0) to the entrance of Newport Bay at Mile 96.4 (Fig. 19). It is characterized by short sandy beaches bounded by rocky headlands ("pocket beaches"). Some of the headlands act as complete barriers to the longshore transport of littoral sand. Dana Point, Abalone Point (Mile 92.1) and the east jetty at the entrance to Newport Bay are a few examples. Other headlands that only extend offshore to shallow depths or are not continuous along their length allow some of the sand that moves parallel to shore to pass around or through them. The effectiveness of most of the headlands in inhibiting longshore transport is unknown.

Beach behavior in the pocket beaches is affected to some extent by the characteristics of the bounding headlands, especially their length, and probably to a lesser extent their orientation from shore; and by the quantity of stream-borne sand that is discharged between headlands. The plan shape of the shoreline between headlands appears to be dependent upon headland characteristics,

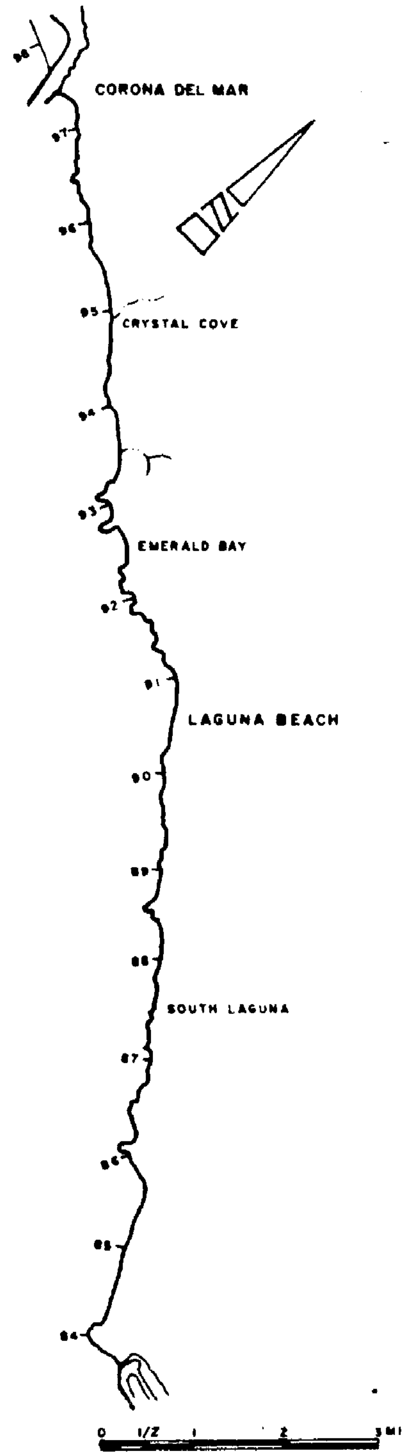

Figure 19. Location map, Laguna Beach Littoral Compartment.

shoreline orientation, and the distance between headlands. Table 17 shows geometric characteristics of the 15 larger headland-bounded beaches in the reach. Historic shoreline position changes that have been measured on these beaches are shown in Figure 20 with the mile designation for the beaches given in Table 17. A zero position is used for the 1934 shoreline, which is the oldest continuous shoreline available for the reach. From Dana Strand Beach to West Street Beach the 1934 shoreline is the oldest. North of there the earliest shoreline was surveyed in 1885 except at Pelican Point Beach where the first shoreline was surveyed in 1875.

The position of the late 1800's shoreline is probably real, indicating there was a significantly reduced volume of sand adjacent to the seacliffs at that time in comparison to the late 1900's. The shoreline change trend at Pelican Point Beach for the period 1875 to 1934 is similar to the 1885 to 1934 trend at beaches south of there, suggesting but not verifying, that the late 1800's to 1934 advance was real, and is not the result of a large seasonal retreat. If it was caused by large seasonal changes they would have had to be similar at the time of the 1875 and 1885 surveys, but not at the time of most later surveys. This is unlikely. The net shoreline advance between 1875 or 1885 and 1934 increased irregularily north of Aliso Beach (Fig. 21). The largest advance rate, about 3 ft/yr, was at Moro Beach in the north. The smallest, about 0.4 ft/yr was at Aliso Beach.

Only beaches south of Main Beach experienced a net shoreline retreat between 1934 and 1982 (Fig. 20). The retreat was greatest at Dana Strand Beach (about 50 ft) and West Street Beach (about 60 ft). Maximum shoreline advance occurred at Crystal Cove (about 100 ft). Beaches in the northwestern part of this reach tended toward more advance in recent years. Again there does not appear to be a relationship between beach character and shoreline behavior.

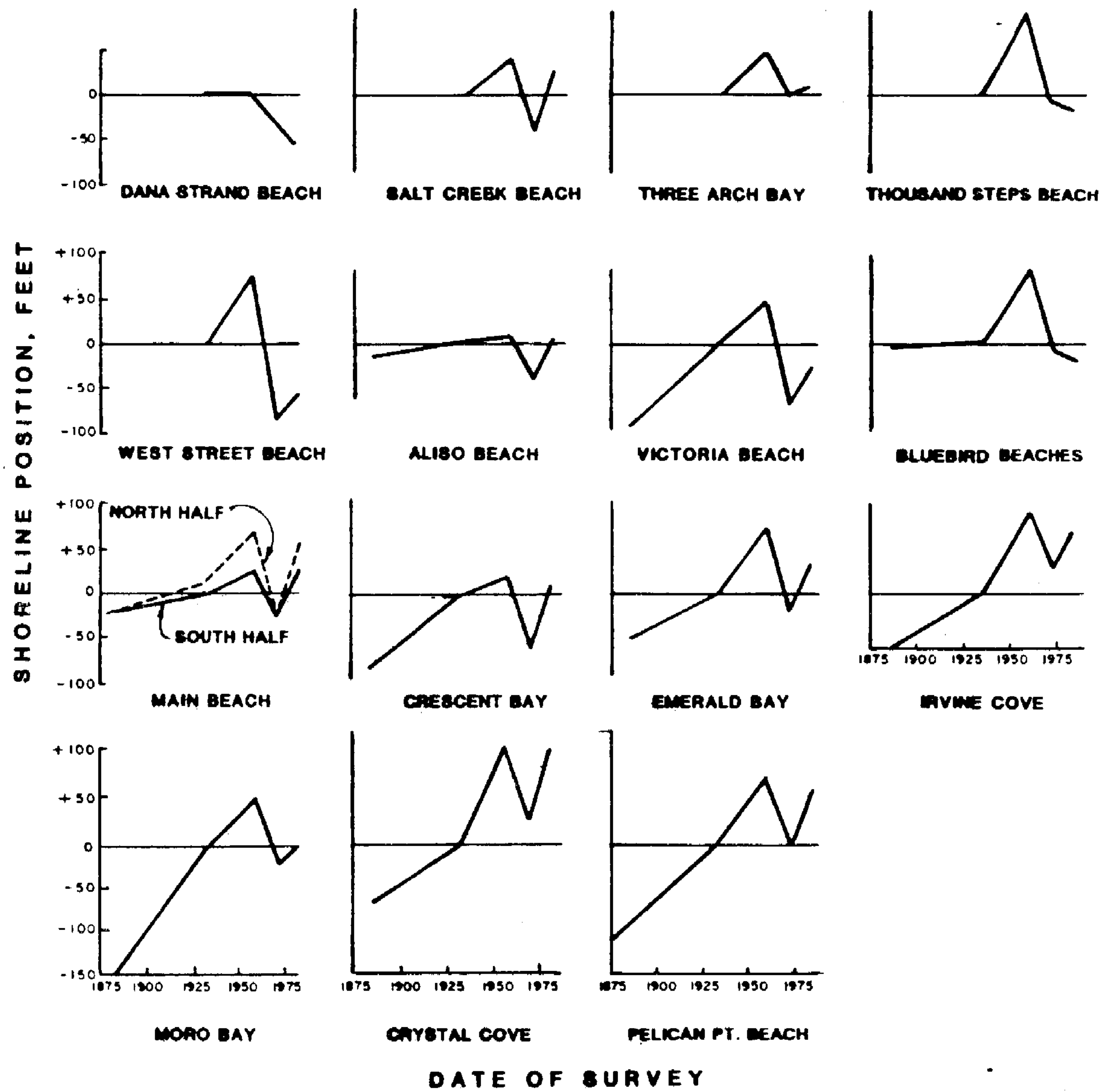

Figure 20. Shoreline positions averaged by beach and referenced to the 1934 shoreline at headland-contained beaches between Dana Point and the entrance to Newport Bay, Orange County, California.

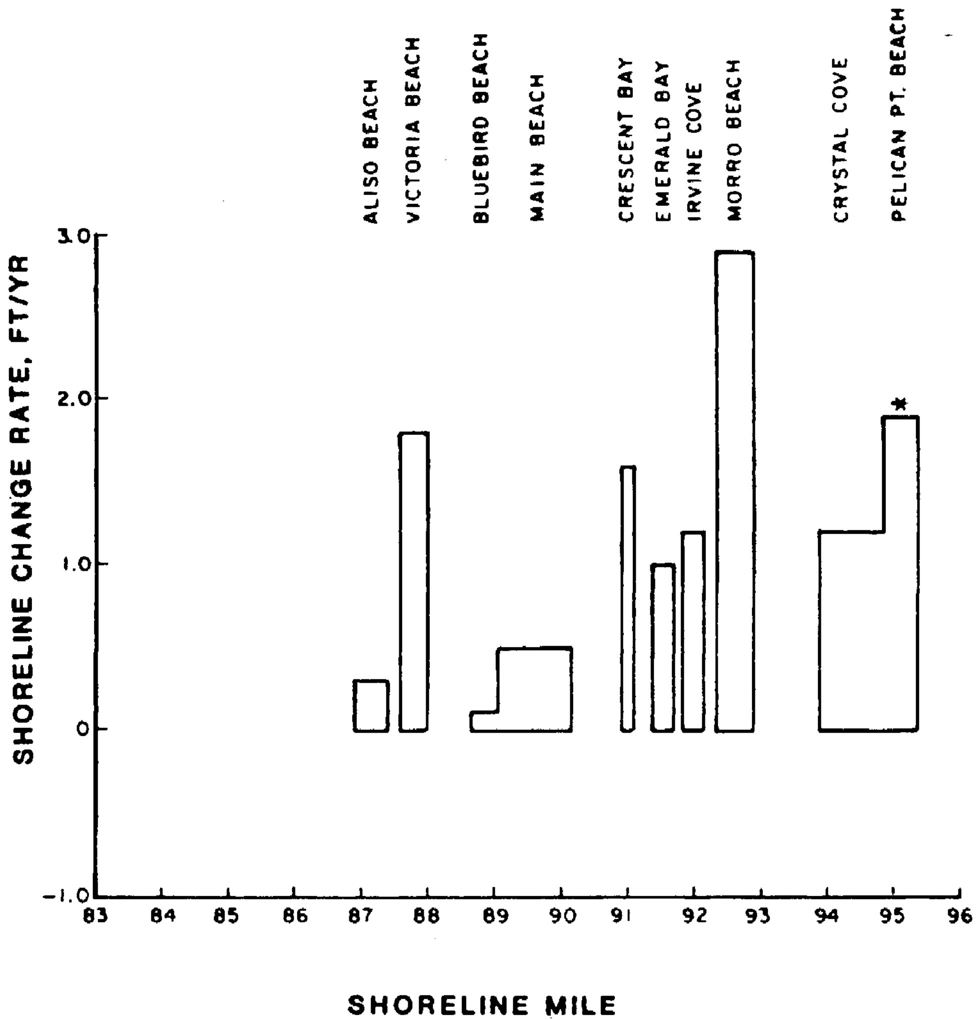

Figure 21. Shoreline change rates for the period 1885 to 1934 (1875 to 1934 at Pelican Point Beach) on 10 beaches south of the entrance to Newport Bay.

TABLE 17. Physical Characteristics of Headland-Contained Beaches in southern Orange County, California

BEACH NAME	MILE LOCATION	LENGTH (feet)	ORIENTATION (degrees)	HEADLAND PROJECTION (feet, g=gradual point) NORTH	SOUTH	STREAM DISCHARGE N = None S = Small L = Large	PLAN SHAPE OF BEACH S = Straight GA = Gradual Arc DA = Deep Arc H = Hook
Dana Strand	83.2-84.0	4000	160	200	650	N	S
Salt Creek	84.0-84.7	3700	160	1800(g)	200	L	S
Three Arch Bay	85.1-85.4	1300	140	700	700	N	D
Thousand Steps	85.7-86.1	2000	135	300	600(g)	N	S
West Street	86.6-86.9	1500	145	200	400	S	S/GA
Aliso	86.9-87.4	2500	140	800(g)	200	L	GA
Victoria	87.6-88.0	2100	155	200	300	S	S/GA
Bluebird	88.7-89.1	3100	135	50	200	S/L	S/GA
Main	89.1-90.2	5700	150	300	50	L	H
Crescent Bay	90.9-91.1	1000	115	450	400	N	DA
Emerald Bay	91.4-91.7	1900	120	1000	400	S/L	GA/DA
Irvine Cove	91.8-92.1	1400	115	600	600	S	GA/DA
Moro	92.3-92.9	3400	130	200(g)	1000	L	GA
Crystal Cove	93.8-94.8	5100	120	200	50	L	GA
Pelican Point	94.8-95.3	2600	125	300	200	S	S/GA

The most apparent relationship is between shoreline position change and the alongshore location of the beach. A linear regression analysis of the shoreline position data indicates there is an alongshore gradient in net shoreline change. Beaches in the south part of the Laguna Beach compartment have tended toward net retreat; beaches in the north have tended toward advance. Since some of these beaches are closed or nearly closed systems, the measured alongshore gradient in shoreline change is surprising. Sediment contributions from streams to the beaches does not vary in a consistent way from south to north. As shown in Table 17, some advancing beaches do not even have an upland source of sand. Similarly, beach orientation and headland characteristics do not change in a uniform manner from south to north. Alongshore variations in land subsidence or uplift is also not the answer. Between 1958 and 1976 the relative rate of sea level rise was consistant at 0.008 ft/yr in this reach (Orange County Surveyor, 1976). The 49-yr period from 1885 to 1934 was one in which human-caused modifications to the coastal zone were negligible. Human effects were not significant in the post-1934 period either.

The progressive alongshore change in the shoreline movement rate therefore must be either an artifact of the survey or data analysis procedure, or it must have been caused by an alongshore variation in wave characteristics or sediment availability seaward of the shoreface. If the 4 or 5 shoreline surveys always began in the south or north, and the surveys required many days or weeks to complete, storm or seasonal changes during the survey effort could possibly produce an alongshore gradient in the position of the shoreline. For example, a survey program begun in the south when beaches were narrow in the spring could have reached the northern part of the reach after the beach there had widened. This scenario does not seem likely though, because the alongshore change trends are relatively consistent no matter what time interval is considered, i.e., 1885-1934, 1934-1982 as shown in Figure 20. The 1972 and 1982 shoreline positions obtained from aerial photographs were almost synoptic so the south-to-north trend toward greater advance between 1972 and 1982 cannot be explained by seasonal alongshore changes in these data. An alongshore variation in wave conditions and/or the availability of sediment seaward of the shoreface seems the more likely explanation of the shoreline change gradient near Laguna Beach.

5. Newport Littoral Cell. Newport Littoral Cell is the southeastern one-half of what was once the contigious San Pedro Littoral Cell (Fig. 22). Before 1889 the San Pedro Littoral Cell extended from Point Fermin to Corona Del Mar. The north half of the Cell was later greatly modified. Today coastal processes north of Anaheim Bay are almost completely controlled by artificial structures. Waves are blocked by the Los Angeles-Long Beach Breakwater which reduces littoral sediment transport. Sand delivery is reduced in the Los Angeles and San Gabriel Rivers as a result of sediment impoundment behind dams. Sediment transport capacity is reduced in the rivers by flood flow regulation. Jetties at Anaheim Bay eliminate sand transport across the bay entrance. From Long Beach to Point Fermin the sandy beaches have been replaced by harbor structures. South of Long Beach to Seal Beach the coast has been segmented by jetties and groins. Beach replenishment projects dominate the sand supply aspect of beach behavior in that region.

Newport Littoral Cell is located south of the entrance to Anaheim Bay (Fig. 22). It is less affected by human intervention than the reach north of the entrance with the coastal processes mostly responsible for molding the shoreline. Newport Littoral Cell is bounded by complete barriers to the

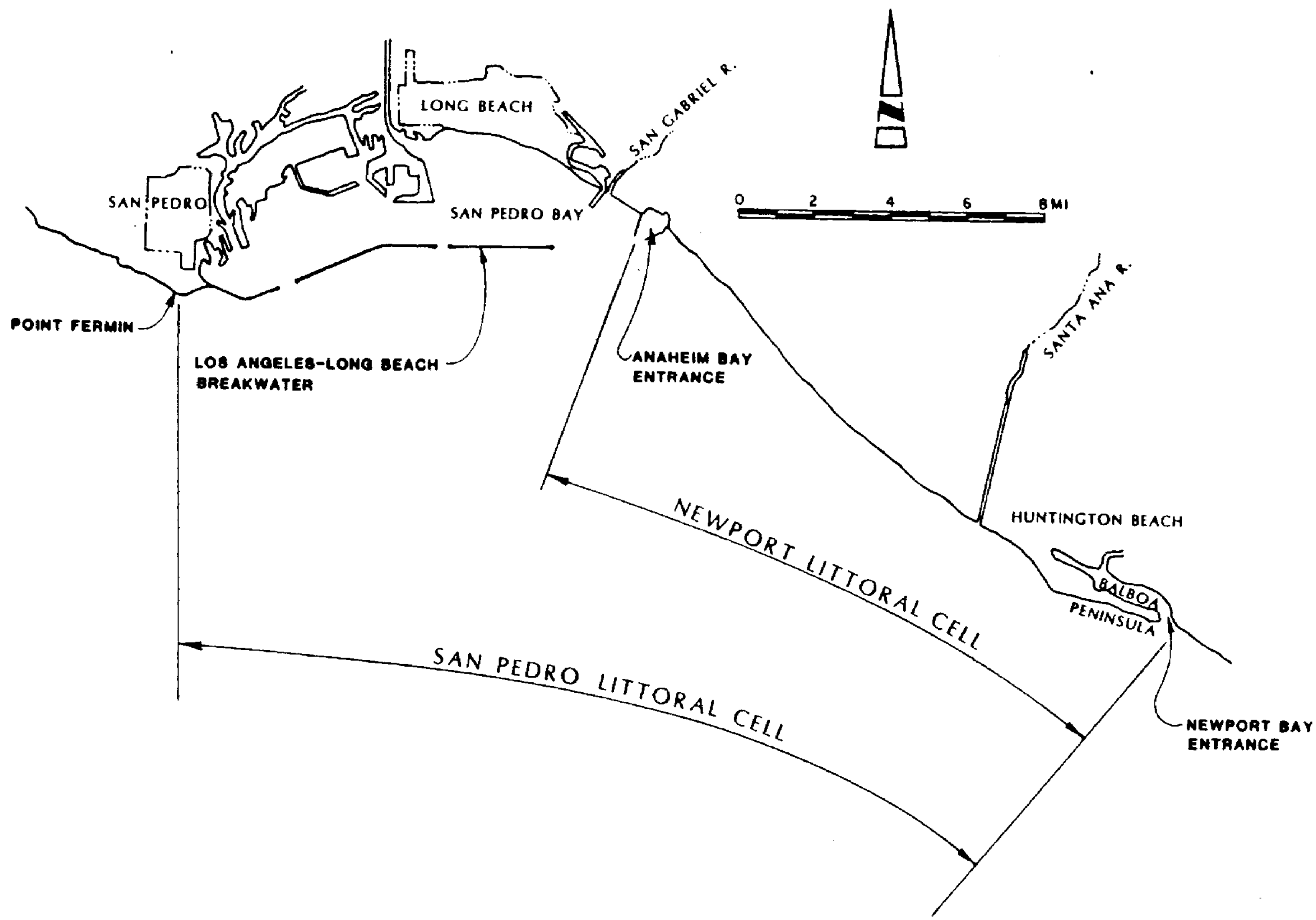

Figure 22. San Pedro Littoral Cell showing location of Newport Littoral Cell.

longshore transport of sand (Fig. 23). Its southeast boundary is the west jetty at the entrance to Newport Bay. The east jetty at Anaheim Bay, 15.6 mi away, is its northwest boundary. The shoreline of the Newport Littoral Cell is not in equilibrium. At some locations the shoreline is advancing, at others it is retreating.

Shoreline coverage on the NOS maps is not uniform throughout the Newport Cell. Only three surveyed shorelines are available along its northwest reach (1959, 1971 and 1982). A longer period (1874-1982) with up to five surveyed shorelines is available in the southeast. Table 18 shows the survey dates and the average shoreline change rates between surveys by shoreline mile.

TABLE 18. Shoreline Changes[1], Newport Littoral Cell

Shoreline Increment, Miles North of US-Mexico Border	Survey Dates					
	1874 to 1926	1874 to 1959	1926 to 1959	1959 to 1971	1971 to 1982	1959 to 1982
96.7-97.0			+13.7	-1.05	-2.05	-1.52
97.0-98.0			+11.5	-6.9	+0.54	-3.34
98.0-99.0	+3.6	+7.35	+13.2	-7.8	-0.30	-4.21
99.0-100.0	+1.27	+4.75	+10.2	-11.4	+3.2	-4.42
100.0-101.0	-0.23	+1.21	+3.45	+4.09	+3.24	+3.36
101.0-101.8		+2.42		+7.70	+0.50	+4.25
102.0-103.0		+3.11		+5.62	+3.30	+4.51
103.0-104.0		+2.33		-0.18	+2.93	+1.78
104.0-105.0		+1.84		-0.10	+1.36	+4.37
105.0-106.0		+1.71		-6.0	+13.44	+3.3
106.0-107.0		-0.99		-5.93	+3.25	-1.54
107.0-108.0		-0.61		-4.94	+8.52	+1.50
108.0-109.0				-1.56	+6.98	+2.52
109.0-110.0				+4.73	+5.24	+4.97
110.0-111.0				+5.33	+2.86	+4.15
111.0-112.0				+14.50	+8.07	+11.42
112.0-East Jetty				+5.11	-3.13	+1.17

[1]average shoreline change rate in feet/year for survey period shown, shoreline changes within period varied from this value

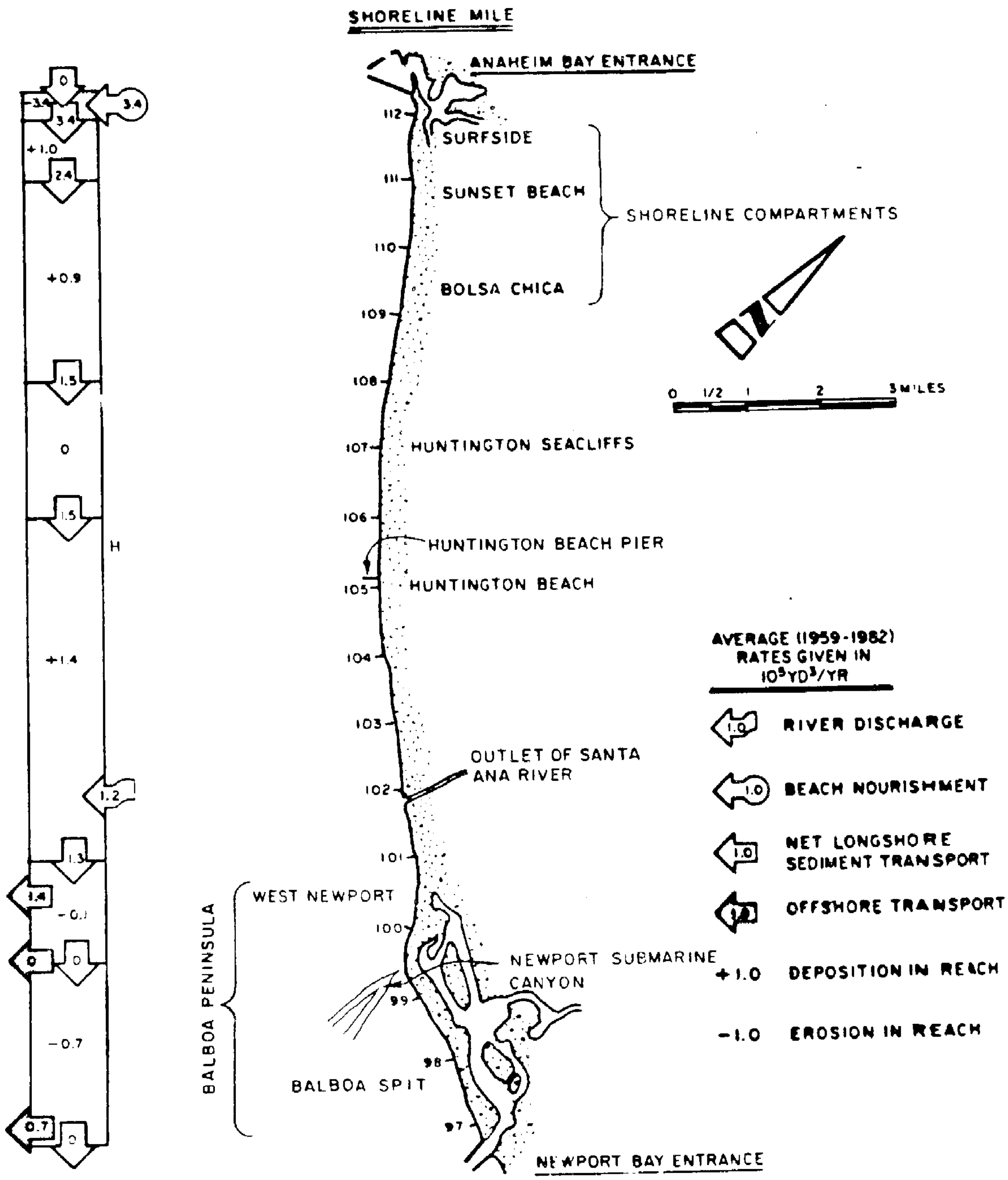

Figure 23. Shoreline mile designations, Newport Littoral Cell; and sediment budget for the period 1959 to 1982 obtained using shoreline position data from NOS maps.

Table 19. Beach Replenishment, Surfside and Sunset Beach[1, 2, 3]

Year Placed	Volume Placed ($10^6 yd^3$)	Cumulative Volume in $10^6 yd^3$
1945-1948	1.42	1.42
1956	0.87	2.29
1964	4.0	6.29
1971	2.3	8.59
1979	1.6	10.19
1982	1.5	11.69
1983-1984	0.75	12.44

1 Corps of Engineers records (A. Fuentes, 1986)
2 All beachfill placed between Mile 111.0 and MIle 112.3
3 Beach greatly widened between 1945 and 1984 southeast of Mile 112.0

a. Sources of Sand. The four main sources of sand reaching the Newport Littoral Cell since 1874, have been:

(1) Beach replenishment at Surfside and Sunset Beach (Mile 111 to Mile 112.3). About 12.4 x 10^6 yd^3 was placed since 1945 (Table 19), most of it at Surfside (Mile 112 to 112.3). About 7.9 x 10^6 yd^3 were placed in the period covered by shoreline surveys from 1959 to 1982. This is an average placement rate of 3.4 x 10^5 yd^3/yr.

(2) Beach replenishment at West Newport Beach (Mile 99.6 to Mile 101.3). About 1.3 x 10^6 yd^3 was placed between 1959 and 1982, or an average 5.6 x 10^4 yd^3/yr (Table 20).

(3) Beach Replenishment along Balboa Peninsula (Mile 96.7 to Mile 99.6). About 7 x 10^6 yd^3 was placed on the beach between 1919 and 1935 and about 6.3 x 10^6 yd^3 was placed between the shoreline survey years of 1926 and 1959. This is an average 1.9 x 10^5 yd^3/yr (Table 20) for that survey period.

Table 20. Beach Replenishment, Newport Beach[1]

Year Placed	Volume Placed ($10^6 yd^3$)	Location (shoreline mile)[2]
1919-1930	1.22	96.7-99.6
1929	unknown, probably 0.1	96.7-97.5
1933-1935	1.45	99.6-100.7
1934-1935	4.28	96.7-99.6
1965-1967	0.255	99.6-100.9
1968	0.184	100.7-100.8
1969-1970	0.572	100.3-101.3
1973	0.272	100.1-100.2
1919-1973	Total = $8.33 \times 10^6 yd^3$	96.7-100.8

[1]from Shaw (1980)

[2]Newport Pier and Newport Submarine Canyon at Mile 99.6

(4) Coarse sediment discharge at the Santa Ana River outlet (Mile 101.8). Brownlie and Taylor (1981) estimate 1.8×10^5 yd^3 are annually discharged under present conditions. Yearly fluctuations about this average are great. For example, Brownlie and Taylor assumed 4×10^6 yd^3 were carried to the ocean in 1969. Kroll (1975) estimated the mean annual coarse-sediment discharge for 1941 through 1971 at 1.9×10^5 yd^3/yr.

Net volume changes, $\Delta V/\Delta t$, in the cell are given in Table 21. They were approximated using Equation 1 with $\Delta S/\Delta t$ from Table 18, h_s assumed to be 45 ft (35 ft below MHW; 10 ft above MHW), and l as given by compartment in Table

[1]from Shaw (1980)

[2]Newport Pier and Newport Submarine Canyon at Mile 99.6

18. An addition or loss of 8,800 yd^3 of sediment is assumed to accompany, respectively, a net 1-ft advance or 1-ft retreat of the shoreline in a 1-mi long compartment.

Using the V/ t data in Table 21 the longshore transport gradient in the cell can be approximated using the 1874 to 1959 data set from Mile 108 downdrift to Mile 96.7. The gradient on Newport Spit can be approximated from Mile 101 downdrift to Mile 96.7 for the 1926 to 1959 period. The gradient for the entire cell can be approximated for the 1959 to 1982 period.

Data given in Table 21 are based on the assumption that the shoreline was at its seasonal mean position. Considering the complete data set available between 1959 and 1982, the maximum expected error in sediment volume for 1-mi long compartment is $\pm 1.1 \times 10^4$ yd^3/yr-mi. This is equal to a practical uncertainty of $\pm$ 30 ft.

b. Causes of Shoreline Change. Shoreline position changes shown on the NOS maps can be explained in a semi-quantitative way when the net sand contributions and losses are considered. Use of the seven compartments shown in Figure 23 simplifies that task. Coastal processes in each of the compartments plays a role in shoreline behavior elsewhere in the cell, and in the determination of the overall plan shape of the shoreline of the cell. The behavior of the shoreline, and the consequences of modifying that behavior at one location in the cell, cannot be fully understood unless conditions throughout the cell are understood.

TABLE 21. Sediment Volume Changes, Newport Littoral Cell[1, 2]

Shoreline Mile, North of US-Mexico Border	Survey Interval 1874-1959	1926-1959	1959-1971	1959-1982	1971-1982
96.7-97		3.6	-0.3	-0.4	-0.5
97-98		10.1	-6.1	-2.9	0.5
98-99	6.5	11.6	-6.9	-3.7	-0.3
99-100	4.2	9.0	-10.0	-3.9	2.8
100-101	1.1	3.0	3.6	3.0	2.9
101-102	2.1		6.8	3.7	0.4
102-103	2.7		5.0	4.0	2.9
103-104	2.1		0.6	1.6	2.6
104-105	1.6		4.8	3.8	2.9
105-106	1.5		-5.3	2.9	11.8
106-107	-0.9		-5.2	-1.4	2.9
107-108	-0.5		-4.4	1.3	7.5
108-109			-1.4	2.2	6.1
109-110			4.2	4.4	4.6
110-111			4.7	3.7	2.5
111-112			12.8	10.1	7.1
112-112.3			1.4	0.3	-0.8
		Total	4.3	28.5	55.9

[1] in 10^4 yd^3/yr; positive = sediment gain, negative = sediment loss

[2] obtained from shoreline change rates listed in Table 18.

(1) Surfside Feeder Reach (Mile 112.0 to Mile 112.3). Between 1959 and 1982 an average 3.4×10^5 yd^3/yr of beachfill was artificially placed on this reach (Table 19). In that time span the shoreline fluctuated greatly about a fixed mean location, but the beach volume remained constant indicating beachfill was carried away at the same long-term rate at which it was placed. The appropriate nourishment rate was therefore employed to maintain the shoreline at Surfside. Most of the beachfill was likely carried to the east at a net longshore sediment transport rate of 3.4×10^5 yd^3/yr. This assumes offshore transport was negligible which is not necessarily the case. The offshore loss rate, if any, is unknown.

Wave reflection from the east Anaheim Bay jetty increased the net longshore sediment transport rate at Surfside. About thirty percent more beachfill was apparently required to maintain a stable shoreline at Surfside than would be required if the longshore component of wave energy was not enhanced by reflected waves. Without the reflective influence of the jetty, the natural longshore transport rate at Surfside would probably be close to the 2.4×10^5 yd^3/yr-south it was at Sunset Beach (see below). An average annual savings of about 1×10^5 yd^3 could be realized if jetty reflections were completely eliminated.

(2) Northwest Sunset Beach (Mile 111 to Mile 112). This reach accreted at an average annual rate of 1×10^5 yd^3. Shoreline advance averaged 11 ft/yr (Table 18). Of the 3.4×10^5 yd^3/yr that entered the Sunset Beach reach from Surfside only 2.4×10^5 yd^3/yr was transported out at the south end. This suggests the entering net longshore sediment transport rate of 2.4×10^5 yd^3/yr, without enhancement from wave reflection off the east Anaheim Bay jetty, would suffice to maintain a stable (non-advancing) beach at Sunset.

The 2.4×10^5 yd^3/yr net longshore sediment transport rate at Mile 111, although approaching its "natural" average for that location, appears to be still affected by the s adowing effect of the Los Angeles - Long Beach Harbor breakwater (Fig. 22).

Sunset Beach is wholly dependent upon the beachfill placed at Surfside for its existence. If the beach nourishment program was terminated an average 25 to 30 ft/yr retreat of the shoreline could be expected. A hook-shaped shoreline would evolve downcoast of the Anaheim Bay jetties. Unless the shoreline was stabilized the evolution of the hooked bay would not end until the shoreline had retreated well past the present line of houses facing the ocean.

(3) Bolsa Chica Reach (Mile 108 to Mile 111). This reach is a relatively narrow barrier that borders the Bolsa Chica wetlands. Between 1959 and 1982, the shoreline at Bolsa Chica advanced an average 4 ft per year (Fig. 3). The net longshore sediment transport rate appears to decline to the southeast at Bolsa Chica (Fig. 23) with the reduction from about 2.4×10^5 yd^3/yr at Mile 111 to about 1.5×10^5 yd^3/yr at Mile 108. About 0.9×10^5 yd^3 of beachfill placed on the beach at Surfside was annually deposited at Bolsa Chica. This translates to an average of between 5 and 6 yd^3 of beachfill deposited from north to south along each lineal foot of Bolsa Chica shore each year.

(4) Huntington Cliffs (Mile 106 to Mile 108). This reach, which projects slightly seaward of the general trend of the shoreline (Fig. 24), experienced only a slight shoreline retreat since 1874. The retreat (Table 21) was greatest where the seacliffs were actively eroded (Mile 106 to Mile 107.5). Between 1874 and 1959 the net loss averaged about 12×10^3 yd^3/yr. In the beach nourishment period following 1959 (Table 19) the net loss averaged 1×10^3 yd^3/yr, possibly because of the nourishment, but also because

the seacliffs between Mile 107.0 and Mile 107.5 had been protected by a revetment.

Between 1959 and 1982 the net longshore transport rate at Mile 106 averaged about 1.5 x 10^5 yd^3/yr-southeast. Beachfill was not deposited there. The net longshore sediment transport rate along the Huntington Cliff reach did not vary in an alongshore direction and was probably near the "natural", or pre-development rate in the littoral cell.

Today, as shown in Figure 24, the Huntington Cliffs are the only high-ground region in the cell directly exposed to ocean wave activity. Some of the alongshore sediment transport gradient in the Bolsa Chica reach is probably controlled by the protruding shoreline of the Huntington Cliffs. In recent geologic time most of the coast of southern California has experienced a net retreat as sea level has risen. Landforms such as the Huntington Cliffs apparently have eroded at a lesser rate than neighboring, low-lying floodplains. The seacliffs are the seaward edge of one of six high-ground regions separating four pre-historic outlets and the present outlet of the Santa Ana River (Fig. 24).

The location of Huntington Cliffs in the middle of the Newport Cell suggest they are acting in concert with the east jetty at Anaheim Bay and the Huntington Beach Pier or the Santa Ana River jetty to fix the shoreline orientation of the cell northwest of Balboa Peninsula. The seacliffs are therefore a most important control on the plan shape of the shoreline in the cell. Without the seacliffs the cell shoreline would probably trend toward an embayed shape instead of its convex shape. Should efforts be made to stabilize or advance the shoreline at Huntington Cliffs, those efforts will likely have major positive implications elsewhere in the cell.

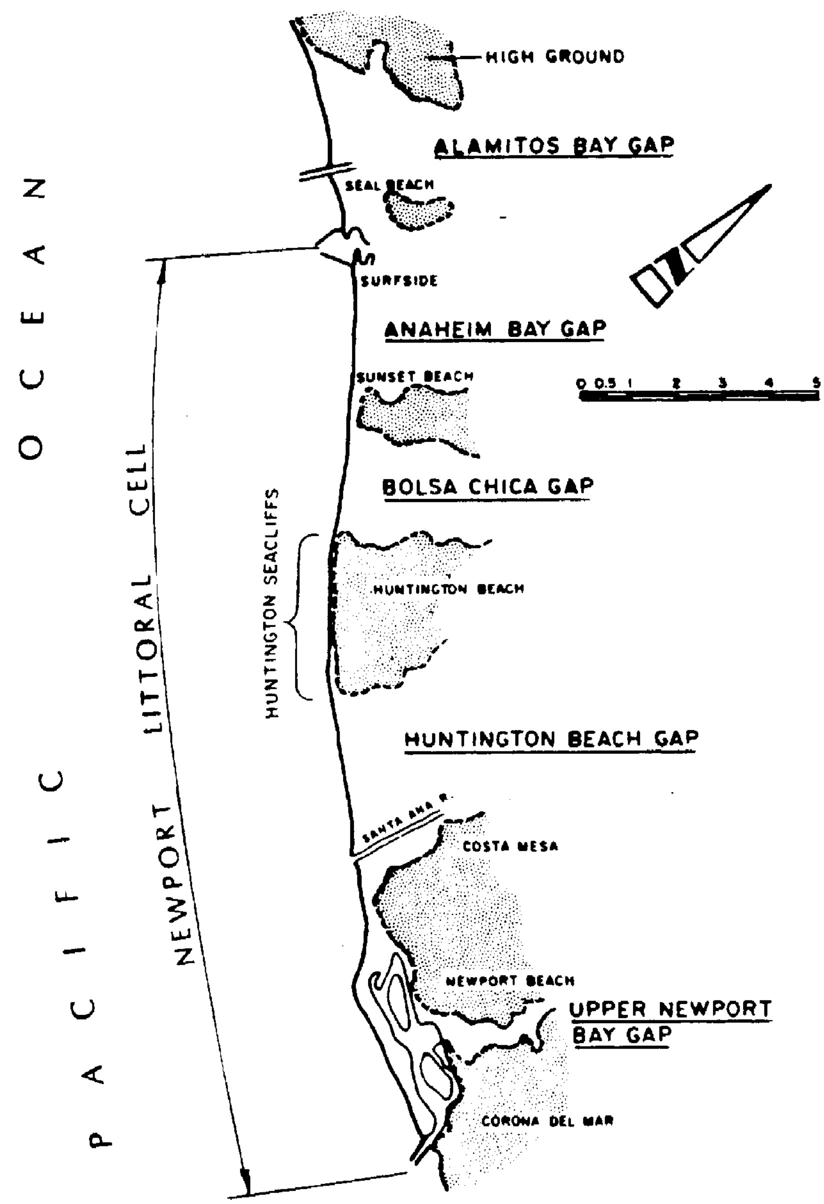

Figure 24. Historic floodplain outlets (gaps) of Santa Ana River showing apparent major control of Huntington Seacliffs on the convex-seaward shape of the shoreline in the Newport Littoral Cell.

(5) Huntington Beach (Mile 101 to Mile 106). This reach has been greatly affected by human interventions. In 1874 the shoreline was near the seacliffs from Mile 104.7 to Mile 106. Since then two coastal structures have created conditions conducive to sand deposition (Table 22). The Huntington Beach Pier at Mile 105.1 acts as a permeable groin. It is 1950-ft long and 25-ft wide with 3-24 inch diameter piles 8-ft apart per bent on a 22-ft bent spacing. Wave energy dissipated on the piles reduces the longshore current speed and the sediment-mobilizing capacity of the waves landward of the breakers. The longshore movement of sediment is consequently reduced at and immediately downdrift of the pier. Following pier construction early in this century the shoreline and shoreface near the pier advanced seaward. This was the only open-ocean pier between the US-Mexico border and Pt. Fermin that had a major effect on shoreline position. The net longshore sediment transport rate at the pier prior to its construction was probably near 1.5×10^5 yd^3/yr-southeast, similar to the rate at the updrift seacliffs reach between 1959 and 1982.

Jetties at the Santa Ana River outlet (Mile 102.2) also had a major effect on shoreline behavior in this reach. They acted to contain sand moving in a southeasterly direction. Shoreline advance in the 2.9-mi long reach between the pier and the northwest jetty was nearly constant after 1959, the date of the first survey after both the pier and jetties were constructed. The northwest jetty held the shoreline at the downdrift end of the Huntington Beach reach; deposition at the pier controlled it at the north end.

The two structures appear to have acted in harmony to advance the shoreline. Neither structure was designed for shoreline stabilization purposes, but much could be learned about the functional behavior of structures by studying them

Table 22. Apparent Effects of Structures in Newport Littoral Cell

STRUCTURE	SHORELINE MILE	APPARENT EFFECT
West Jetty, Entrance to Newport Bay	96.7	Prevents sedimentation problems in Newport Bay channel, possibly deflects $7 \times 10^4 yd^3$ of littoral sand offshore annually.
West Newport Groins	100 to 101	Stabilize the West Newport shoreline, possibly deflect 1.4×10^5 yd^3 of littoral sand offshore annually.
Jetties, Santa Ana River Entrance	102	Maintain the Talbert Channel entrance and act to stabilize northwest beaches possibly as far away as Mile 101.
Huntington Beach Pier	105	Appears to act as a permeable groin causing the local shoreline to advance.
Beach Nourishment, Feeder Source at Surfside	112 to 112.7	Annual artificial addition of $3.4 \times 10^5 yd^3$ of sand producing shoreline advance as far downcoast as the Santa Ana River.
East Jetty, Anaheim Bay	112.7	Wave reflection increases longshore sand loss at Surfside by an average $1 \times 10^5 yd^3/yr$.

as a system. The updrift structure is permeable. It holds some of the sand that reaches it, but allows the rest to move downcoast toward the relatively short impermeable downdrift jetty. The jetty allows sand transported parallel to shore to pass seaward of it. Together the pier-jetty system contains a nearly-straight beach.

Between 1874 and 1959 an average of about 0.9×10^5 yd^3/yr was deposited in the 5-mi long Huntington Beach reach. Deposition probably increased after the pier and jetty were constructed early in the 20th Century. From 1959 to 1982 the deposition rate was 1.4×10^5 yd^3/yr. Considering the net 1.5×10^5

yd^3/yr that, on average, entered this reach between 1959 and 1982 at Mile 106, the portion of that amount that continued through the reach was only about 0.1×10^5 yd^3/yr-southeast at Mile 101. This volume is within the uncertainty range of the sediment budget methodology used.

It appears that almost all of the beachfill placed at Surfside is deposited between Mile 112 to Mile 102 and does not reach West Newport and Balboa Peninsula. This has some important implications. If correct, the Santa Ana River is the primary natural source of sand for the beaches at West Newport (and possibly beyond). Should the Santa Ana River source of sand be compromised, West Newport could feel the effect.

(6) West Newport (Mile 101 to Mile 99.6). Since at least 1920 the primary source of sand reaching West Newport has been the Santa Ana River. Newport Submarine Canyon is the primary control on shoreline orientation at West Newport. Sand carried to the southeast end of West Newport has historically passed to Balboa Peninsula or into Newport Submarine Canyon, the portion going to each dependent largely upon beach width. Except during major floods, the sediment in the Santa Ana River was carried into Lower Newport Bay before the river entrance jetties were constructed in 1920. Major floods that occurred in the wet periods of 1884-1891 and 1914-1916 very likely discharged directly to the ocean near Mile 102, the present entrance location.

Because the shoreline at West Newport has a more southerly orientation, the potential longshore transport capacity there is probably less than it is at Huntington Beach. A large delta created during a major flood, such as the 1969 flood, however, will degrade at a rate somewhat exceeding that potential rate. Waves will break on the delta at a greater angle with respect to the shore than if the delta were absent and longshore transport will be increased until the delta is gone. No delta of appreciable size exists off the Santa Ana River outlet today. Some or much of the deltaic sediment volume produced by past major floods was likely carried rapidly into Newport Submarine Canyon.

From 1874 to 1926 the shoreline at West Newport was stable. Sediment reached it from the northwest. Most probably moved through West Newport to Balboa Peninsula and, sometimes, into Newport Submarine Canyon. The period 1926 to 1959 was one of growth for West Newport. It gained an average 6×10^4 yd^3/yr, primarily in the region near the head of Newport Submarine Canyon. Most of that material came from beach replenishment on Balboa Spit (Table 20).

Six groins were constructed at West Newport in 1968 (Table 22) and between 1965 and 1970, about 1×10^6 yd^3 of sand were placed on the beach at West Newport. Sand of the beachfill came (artificially) from the Santa Ana River channel. Still, an average 4×10^3 yd^3/yr was lost between 1959 and 1971. When the artificially-placed beachfill is removed from consideration, the average total net loss rate was 0.9×10^5 yd^3/yr. A part of that loss may have been fine sizes winnowed when the beachfill was reworked. From 1971 to 1982 West Newport experienced a slight net sediment loss (about 1×10^4 yd^3/yr). Two groins were constructed in 1973 and 2.72×10^5 yd^3 of sand were coincidentally placed on the beaches.

The sand volume that entered and left West Newport is difficult to quantify. Losses to Newport Submarine Canyon before 1959 were probably significant after major influxes of sand reached the shore adjacent to the canyon, either from the Santa Ana River or from nearby beach replenishment projects. After 1959 the canyon was not as active a sink for littoral sand. From 1959 until 1968 there were no major floods in the river. After 1968, and especially after the flood of 1969, large slugs of sand that moved toward the canyon may have been deflected offshore at the groins. The sand contribution from the Santa Ana River probably averaged between 1 and 2 x 10^5 yd^3/yr based on continuity considerations. The net longshore transport rate is assumed to be 1.3 x 10^5 yd^3/yr (Fig. 23 and 25), which is toward the lower end of the average river-contribution range. A detailed analysis of conditions at Balboa Peninsula is needed before a better estimate of the net longshore transport rate at West Newport can be made.

(7) Balboa Peninsula (Mile 99.6 to 96.7). Between 1874 and 1926 this mostly undeveloped reach was slightly accretional (about 3 to 4 x 10^4 yd^3/yr), even when beachfill (Table 20) is considered as an addition. Prior to 1918 when construction of the west jetty began, sand moved alongshore to the east end of the spit and into Lower Newport Bay. The volume that moved into the bay before 1918 is unknown. Clearly, though the net longshore transport rate was greater than the 3 or 4 x 10^4 yd^3/yr-southeast suggested by the accretion rate on the ocean side of the spit.

Between 1926 and 1959 the accretion rate on Balboa Peninsula averaged 2.5 x 10^5 yd^3 annually. Considering the 6 x 10^6 yd^3 that was artificially added when Lower Newport Bay was dredged, an average 6 x 10^4 yd^3 (or more) was naturally transported into this compartment from West Newport. This net longshore sediment transport estimate may be low because some of the material moving from West Newport may have been lost to Newport Submarine Canyon.

The annual average loss in the 23-yr long period between 1959 and 1982 was about 0.7 x 10^5 yd^3/yr. Very little was lost to Newport Submarine Canyon.

Apparently most of the lost volume was deposited offshore the West Jetty of Newport Bay. After 1968 it is possible only a small volume of sand passed to Balboa Peninsula because it was trapped and deflected offshore at the newly-constructed West Newport groin field. Felix and Gorsline (1971) suggested such transport based on a large, thin sand deposit they found seaward of the groins.

Sediment transport rates and transport paths at West Newport are the least well known in the littoral cell. Yet, they are very important. If sand is being deflected offshore by the groins and none is passing to Balboa Peninsula, the estimated 7×10^4 yd^3/yr loss of sand from Balboa Spit calculated using the NOS map shorelines will continue. Even the wide beach that exists today, thanks to beach replenishment in the early part of this century, will not last forever. An average 2 to 3 ft/yr retreat can be expected and within a few generations the effects will be very noticable. The solution may not be massive beach replenishment programs, either at or downcoast of West Newport. A huge overload on the littoral system could move significant quantities of the beachfill into the head of Newport Submarine Canyon thereby reducing its effectiveness. As a beach widens landward of a canyon head the potential for littoral sand losses to the canyon increase because of an increase in slope from the littoral zone to the canyon head.

c. Historic Longshore Sediment Transport Rates. Estimates of potential net longshore sediment transport rates based on wave refraction analyses, and net longshore transport rate estimates based on the sediment budget approach described here yield similar results. Estimates of potential net longshore sediment transport rates in the cell have been made by various investigators. Most of their methods involved a wave refraction analysis and calculations that relate the longshore component of wave energy flux to sediment transport. As shown in Table 23, the calculated potential net longshore sediment transport rates varied from 1.75 to 2.82 x 10^5 yd^3/yr-southeast near Surfside and Sunset Beach (Mile 111 to Mile 112.3). Wave refraction analyses by Hales (1980) indicate the net potential rate decreases to about one-half that at the Santa Ana River mouth.

TABLE 23. Potential Net Longshore Sediment Transport Rates, San Pedro Littoral Cell[1]

Shoreline Mile, North of US-Mexico Border	Longshore Transport Rate, in 10^5 yd^3/yr	Reference	Method
about 125	1.17-east	Inman and Frantschy (1960)	wave refraction analysis assuming natural conditions
111	2.0-east	Seymour and Castle (1984)	wave array
110 to 112	1.75-east	Caldwell (1956)	beach profile analysis
110 to 112	2.82-east	Marine Advisors (1965)	wave refraction
112	2.76-east	Hales (1980)	wave refraction
106	1.92-southeast	Ingle (1966)	averaged tracer
102	1.12-southeast	Hales (1980)	wave refraction
99	1.27-southeast	Hales (1980)	wave refraction
98	4.07-northwest	House Document No. 637 (1940)	dredged material movement

[1]modified from Inman et al (1986)

Two values obtained from the contemporary sediment budget are useful in establishing the pre-development sediment budget for the Newport littoral cell and the historic net longshore sediment transport rates. The net longshore sediment transport rate at Huntington Cliffs, estimated using the continuity approach (Fig. 23), is 1.5×10^5 yd^3/yr - southeast. This is approximately equal to the average potential annual capacity of waves to carry littoral sand to the southeast as obtained in a wave refraction analysis (Hales, 1980). Longshore transport at the seaward-protruding seacliff reach is not significantly affected by present-day updrift (or downdrift) human modifications to the cell such as possible reductions or changes in location of river discharge, the Los Angeles - Long Beach Harbor breakwaters, the jetties at Anaheim Bay, the rate at which beachfill is placed at Surfside, and effects of the Huntington Beach pier and Santa Ana River jetties. Inman and Frautschy (1960; in Inman et al, 1986) estimate the natural net potential longshore sediment transport rate west of Surfside to have been about 1.2×10^5 yd^3/yr prior to any human effects that could have modified it. This suggests the higher 1959-1982 rates in the Surfside through Bolsa Chica reach are artifacts of recent human interventions.

Shoreline position under normal conditions probably varied much more than at present as past sand delivery by rivers fluctuated between wet and dry periods. In wet periods when river discharge exceeded approximately 1.0 to 1.5×10^5 yd^3/yr the longshore transport capacity would not have been sufficient to carry it away and the shoreline would have advanced. In dry periods, when an average 1.0 to 1.5×10^5 yd^3/yr was not carried to the coast, the shoreline probably retreated as the capacity of waves to transport sand exceeded the renewal rate.

The apparent downcoast movement of beachfill placed at Surfside and deposited updrift of the river entrance and its effect on shoreline position is evidence of an important 1959-1982 longshore transport gradient. About 3.4×10^5

yd^3/yr was deposited, non-uniformly, in the 9-mi long reach from Mile 111 to Mile 102. The gradient was partially caused by natural factors. Wave energy and wave approach directions vary along that reach. The natural alongshore gradient averages about 3 yd^3/yr-ft, obtained using the difference between the net longshore transport rate calculated using the sediment budget approach as shown in Figure 23, and the difference in the potential rates suggested by Hales (1980) for Surfside and Huntington Beach (Fig. 25). The approximately 50 percent remaining cause of the alongshore gradient, also about an average 3 yd^3/yr-ft, can be attributed to structures. About half of that was due to localized reflection at the Anaheim Bay jetty. The other half was caused by the "holding" characteristics of the combination Huntington Beach Pier and the jetty at the entrance of the Santa Ana River.

6. South Palos Verdes Littoral Compartment. Beaches in this 5.8-mi long, south-facing reach are backed by seacliffs and contained between headlands. Cabrillo Beach at Mile 126 (Fig. 26) is backed by the San Pedro Breakwater and contained at its east end by a long, high-profile groin. About 0.4-mi to the west it is contained by the headland complex of Point Fermin. From the west end of Cabrillo Beach to Portuguese Point the shoreline has been minimally affected by humans.

In this compartment almost all the 1859 or 1870 shoreline positions are the most landward of all the shorelines surveyed. The most seaward shoreline position is that surveyed in either 1959 or 1982. In many cases the 1982 shoreline, as established using aerial photographs, is at the base of a seacliff. The only two reasonable explanations for the apparent shoreline advance in recent years is there is an error in the earliest shorelines, or

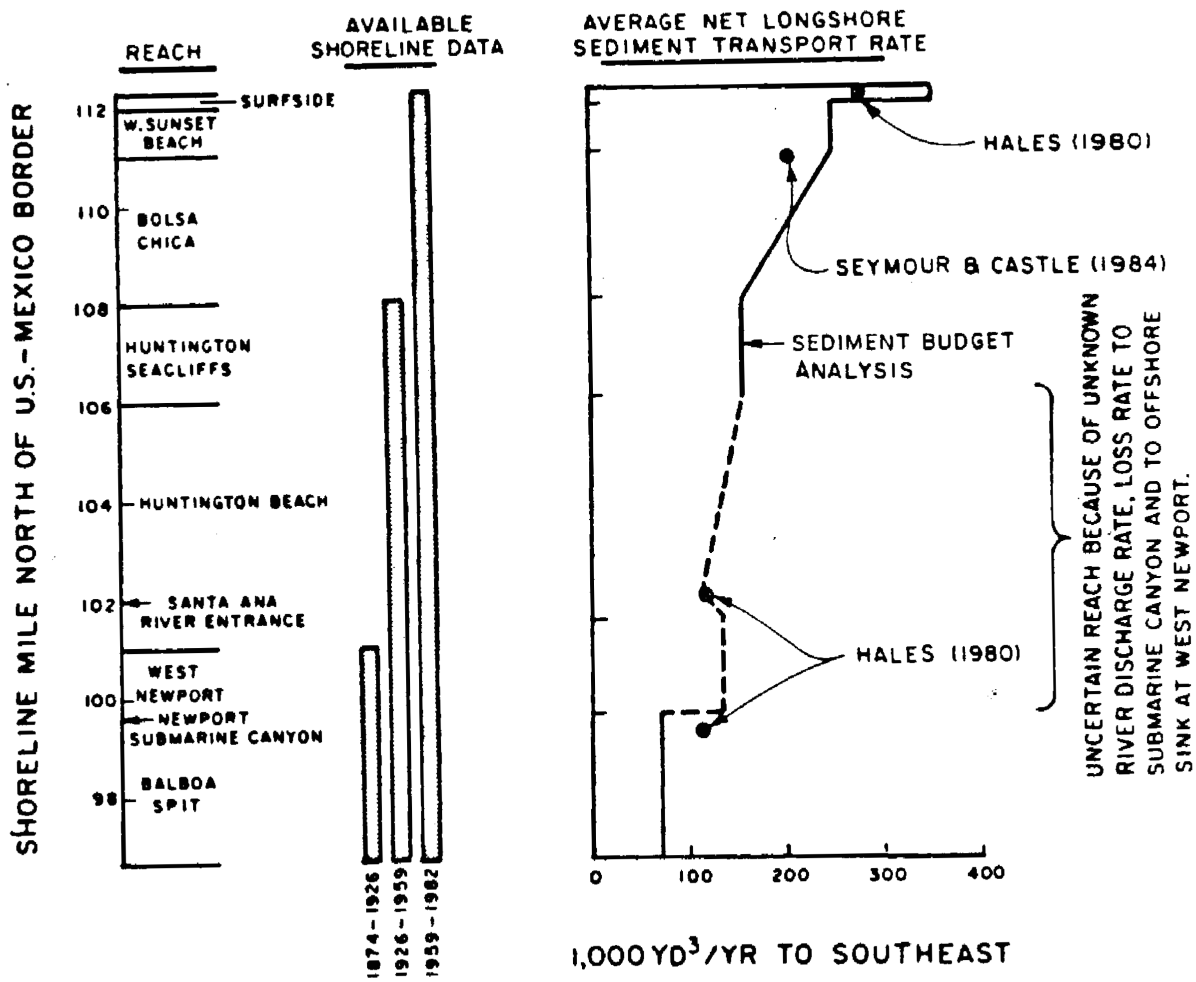

Figure 25. Average net longshore sediment transport rates for the Newport Littoral Cell using two different methods to obtain the rates.

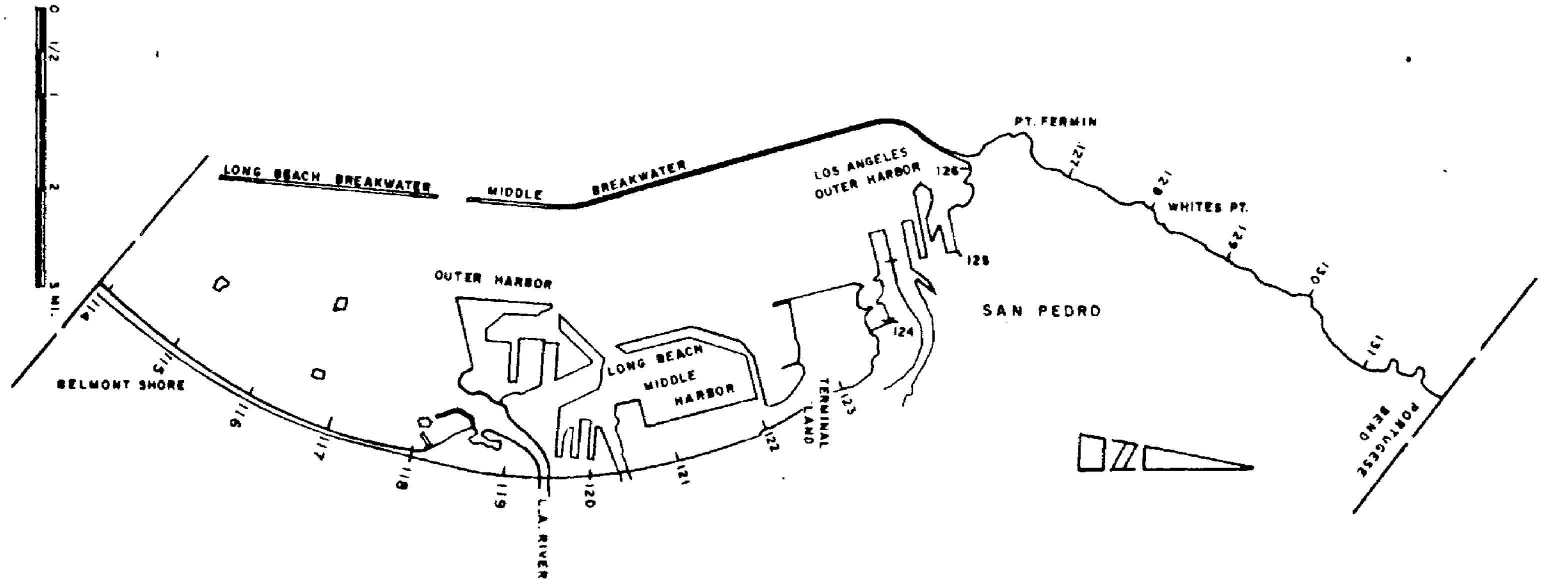

Figure 26. Location map, Cabrillo Beach (at Point Fermin) to Portuguese Point Los Angeles County, California

the land mass behind the seacliff has moved seaward. In some cases the cause of the seaward shift in the shoreline appears to be a movement of the land.

This is best illustrated by the Portuguese Bend landslide just east of Portuguese Point. The land mass there has moved progressively seaward along a 3500-ft long reach. The mean position of the shoreline moved with it as shown in Figure 27. Movement was not at the same rate along the length of the slide, nor did the movement occur at the same time at all locations in the slide area.

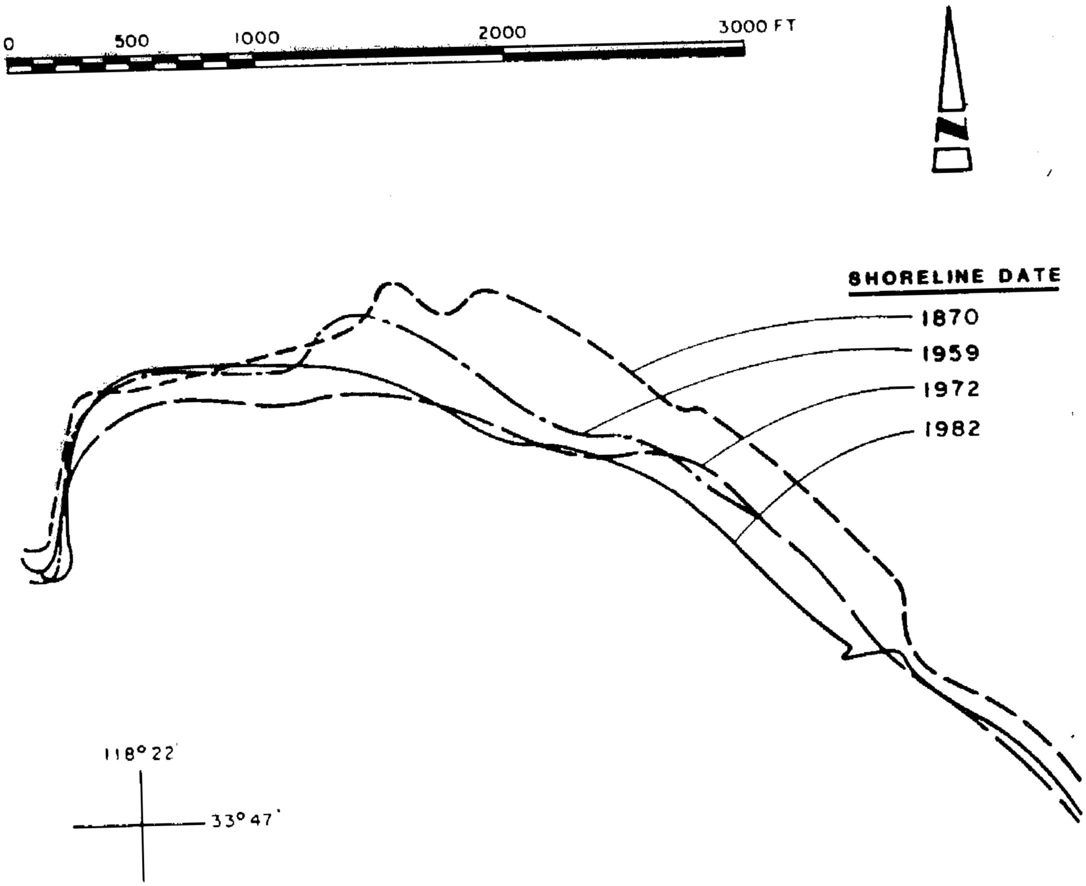

Figure 27. Advance of MHW Shoreline at Portuguese Bend, 1870-1982 (Los Angeles County, California).

IV. SUMMARY AND CONCLUSIONS

Shoreline position maps, some with shorelines dating back to 1851, were prepared in 1984 by the National Ocean Services (NOS) for a 132-mi length of the California coast north of the Mexico border. Basic data used in compiling the maps were historic NOS manuscripts (T-sheets). This investigation, using the shoreline maps, had two objectives. The first objective was to evaluate the maps to determine their accuracy when the net shoreline change and net shoreline change rate were calculated. Net changes in shoreline position are the only useful data that can be extracted from the maps. Seasonal and other reversible changes in shoreline position cannot be obtained because the shorelines were only surveyed once per 10 years or more. The second objective of the investigation was to interpret shoreline behavior at those locations where the net change in position between two or more shorelines exceeded the uncertainty range of the data.

Comparisons of historic shoreline positions on the NOS maps are best used to establish trends in shoreline behavior rather than to establish exact rates of shoreline change. This is because of inaccuracies introduced by survey errors, errors in selecting the MHW shoreline, and data reduction errors. Of more importance there is uncertainty due to the state of the shoreline when the survey was made. To obtain the net shoreline change, the map shoreline position is assumed to be at the midpoint of all seasonal and other reversible excursions of the shoreline. Because it would only coincidentally be at that midpoint when the shoreline survey was made an uncertainty is introduced. Seasonal changes in position can be a maximum 120 ft ($\pm$ 60 ft from the mean.) A comparison of net changes using NOS map shorelines and shorelines obtained from other sources such as aerial photographs and surveyed shore-normal profiles, however, indicates the practical, useful uncertainty range is half the maximum range or about 60 ft ($\pm$30 ft about the actual mean position of the shoreline).

Four littoral cells and two coastal compartments where relatively short beaches are contained between headlands were studied. From south to north they are the US portion of the Silver Strand Littoral Cell, Mission Bay Littoral Cell, Oceanside Littoral Cell, Laguna Beach Coastal Compartment, Newport Littoral Cell, and South Palos Verdes Coastal Compartment. Shoreline behavior as displayed on the NOS maps indicates:

The shoreline along most of the 53-mi long Oceanside Cell is within the practical uncertainty bounds of the NOS maps. At these locations the shoreline has been within 60 to 100 ft of its 1982 position in the past 100 years or so. A 10-mi long reach near Oceanside and a 6-mi long reach south of Dana Point are exceptions where shoreline changes have been larger.

1. <u>Historic Shoreline Advances and Retreats</u>. Nineteenth century shorelines along most of the coast of southern California were landward of shorelines surveyed in the latter part of the twentieth century. In some areas, including much of the Silver Strand Littoral Cell and the Newport Littoral Cell, large beach replenishment efforts were responsible for the advance. Hard structures have also been responsible for shoreline advance.

2. <u>Effects of Coastal Structures</u>. Coastal structures, especially breakwaters and jetties, but also including a recreational pier and groins, have had a significant effect on shoreline behavior in the study region. Shorelines have advanced and retreated as a result of the structures. The shoreline on the

north side of Oceanside Harbor, for example, advanced about 100 ft seaward to a distance 5.5 mi north of the harbor prior to 1960. Dana Point Harbor, constructed in 1970, has caused about 3 mi of shoreline southeast of the harbor to advance. The Huntington Beach Pier and the west jetty at the mouth of the Santa Ana River reduced the net longshore sediment transport rate along a 2.9-mi shoreline and caused it to advance. The pier apparently acts as a permeable groin and the downdrift jetty acts as an impermeable groin that allows bypassing only at its seaward end. Sand being deposited between these structures is artificial beachfill placed at the Surfside feeder beach about 8 mi to the north. The shoreline advance near the Huntington Beach Pier was so great that a condominium was constructed on the beach seaward of a seacliff that had been scoured by waves in historic times.

Artificial beachfill and sand bypassing have prevented large shoreline retreats downdrift of some coastal structures. This is the case at Oceanside where an average 3.2×10^5 yd^3/yr of fill placed south of the harbor has barely maintained the beach in the past 30 years. At Surfside, near the upcoast end of the Newport Littoral Cell, an average of about 3.4×10^5 yd^3/yr of artificial fill were placed between 1959 and 1982 to prevent local shore retreat in the littoral cell. The Long Beach-Los Angeles Breakwater, dams on the Los Angeles and San Gabriel Rivers, and the jetties at Anaheim Bay have eliminated the supply of sand updrift of Surfside. Beach nourishment at Surfside is the only source of sand at the updrift end of the cell today.

Some long, high-aspect coastal structures deflect sand offshore at the expense of nearby shorelines. The jetties at Oceanside Harbor, for example, have deflected sand offshore creating a large deposit in water depths of 12 to 36 or 40 ft. A similar deflection at the west jetty at the entrance to Newport

Bay is apparently responsible for a net loss of littoral material to deep water. Zuniga Jetty at the entrance to San Diego Bay functions in the same way. Sediment moving along the jetty is carried further offshore and into deep water. Only a small amount of coarse-grained sediment is carried seaward at the entrance jetties to Mission Bay, however. Littoral sediment passes through or around those jetties and is deposited in the entrance channel. Periodically that material is returned to nearby beaches.

The construction of the south breakwater at Dana Point Harbor influenced shoreline behavior on beaches to the east. The plan-shoreline disequilibrium induced by constructing the breakwater and effectively moving Dana Point about 1-mi east resulted in a large advance of the shoreline to perhaps 3-mi east of the harbor. Sediment involved in the shoreline advance came from the harbor, from San Juan Creek and from an artificial beachfill. Shoreline changes in the lee of Dana Point Harbor appear to be atypical for crenulate-shaped bays that are modified by changing the location of the updrift headland. Sand usually moves toward the new headland at the expense of downdrift beaches. Erosion has not noticeably occurred east and downdrift of Dana Point Harbor yet. Slow shore retreat at the east end of Capistrano Beach continued at about the pre-harbor rate after the harbor was constructed. If accretion continues in the lee of the harbor without the addition of sand from sources other than San Juan Creek, however, south Capistrano Beach could experience an accelerated retreat in the future.

The east jetty at Anaheim Bay does not appear to be deflecting sand offshore. Instead, waves reflected from it increase the longshore sediment transport rate at Surfside by about $1 \times 10^5 yd^3/yr$. The material moved is costly beachfill that is deposited downcoast at Sunset Beach and further to the southest. Wave reflection from the jetty increases the need for fill material at Surfside by an average 30 percent.

3. Beach Replenishment. The largest beachfill projects in the recent past were constructed using material excavated for reasons other than beach replenishment. These projects were responsible for much of the recent advance of the shoreline in the study area. Inexpensive fill sand from similar sources will not be available in the future. The largest beach replenishment project completed in California, and maybe anywhere in the United States, received sand dredged for another reason. In 1946, 23.6×10^6 yd^3 of material removed from San Diego Bay for navigation purposes was placed in the Silver Strand Littoral Cell near Coronado. The shoreline was artificially advanced over 1000 ft along a 2-mi reach. Within 10 to 14 years of placement the beachfill spread along 10-mi of coast. The project created new land upon which a large condominium complex was constructed. A major beach replenishment project at Newport Beach in the first half of this century was also accomplished using sand dredged for other purposes. Harbor-deepening provided large quantities of fill that was placed on Balboa Peninsula and West Newport. The wide beach that now exists on Balboa Peninsula would probably be impossible to construct today because of cost, difficulties in obtaining a large quantity of fill of proper size, and environmental constraints. In the future large beach restoration and reclamation projects such as these will be more expensive and difficult.

4. River Sediment Discharge. Rivers have historically contributed large quantities of sand to the coast of southern California. Dams and debris basins have reduced that contribution in some rivers to an unknown extent. In

rivers with wide floodplains near the coast, artificial channelization may have increased the discharge of coarse sediment to the coast.

At Oceanside the effect of river discharge on shoreline behavior was most apparent. The San Luis Rey and Santa Margarita Rivers presently discharge to the south and north of Oceanside Harbor. Before 1942, prior to the construction of the harbor, shoreline advances and retreats of up to 300 ft occurred between surveys along a 4 mi reach adjacent to the river outlets. Actual shoreline fluctuations were greater than that. Straight, wave-cut seacliffs behind the beach at Oceanside are evidence the beach was once narrow and the shoreline was against the seacliffs. The period from 1842 to 1883 was exceptionally dry except for the early 1860's and it may have been during this pre-development period that the seacliffs at Oceanside were last cut by waves. During wet periods the shoreline at Oceanside advanced rapidly when large quantities of sand were discharged by the rivers. Development may have coincided with a "wide-beach" period. The present beach width that is being artificially maintained may not represent the long-term average beach width at Oceanside.

5. Pocket Beaches. Beaches contained between headlands, or pocket beaches, are prevalent at a number of reaches in the study area. The Laguna Beach Coastal Compartment is the longest reach containing pocket beaches. It extends 16 mi from Dana Point to the entrance of Newport Bay and long-term (50 to 100 yrs) shoreline behavior in the pocket beaches, surprisingly, does not appear related to: (1) the distance the headlands extend away from the regional trend of the shoreline, (2) the length of the beaches or their orientation, or (3) the presence or absence of a local stream that delivers upland sand to the coast. Shoreline behavior most noticeably varied in an

alongshore direction, seemingly without regard to these controls. All shorelines advanced from 1875 or 1885 to 1934 with the greatest advance on northern beaches. From 1934 to 1982 the northern beaches generally advanced, the shorelines of central beaches were approximately unchanging, while the shorelines of southern beaches retreated. Explanations for this behavior include an alongshore gradient in wave scour (decreasing to the north) or an alongshore gradient in sediment availability seaward of a line connecting the headlands (decreasing to the south).

6. Lagoons. Many relatively high-gradient streams in San Diego County pass through wide, low-gradient lagoons before they reach the ocean. Lagoons nearest La Jolla are mostly filled with sediment that supports marsh vegetation. Further north the filled portion of the lagoons decrease. From Encinitas to Oceanside the lagoons are predominantly open water. The reason for this alongshore change in lagoon filling is unknown, but does not appear related to lagoon size, catchment area of the watershed draining into the lagoon, or sediment yield of the watershed. One possibility is a differential rate of land subsidence or emergence from south to north with a downward tilt to the north.

Lagoon entrances were only open about 40 percent of the time when the NOS shoreline surveys were made. Entrances in the south were open slightly more often than entrances in the north. In almost all lagoons the open entrances were north of the centerline of the lagoon which is a bit surprising because the net longshore sediment transport direction is believed to be toward the south in this area. Common belief is that the outlet of a stream or lagoon controlled by coastal phenomena will most often be at the downdrift end of the shoreline reach through which it discharges.

Shoreline behavior at Agua Hedionda Lagoon, with controlled lagoon outlets, appeared to be directly related to the beach nourishment rate. Sand that entered the lagoon from the littoral zone was periodically removed and placed on the adjacent ocean beach. When the dredging and placement rate dropped below an average 1.25 x 10^5 yd^3/yr the shoreline retreated. It advanced when the nourishment rate exceesed that value. These effects of the beachfill were obvious over a limited reach less than 1-mi long. Beaches further away did not appear affected by variations in the nourishment rate. It is not clear whether the dredging-beach nourishment program at Agua Hedionda is just a sand bypassing effort, in which the net or a portion of the net longshore sediment transport volume is bypassed, or whether backpassing may also be involved. Sand transported to the lagoon may come from beaches both north and south of the controlled entrance.

7. Land Movements. In several areas, including Torrey Pines near La Jolla, various locations at Camp Pendleton, and north of Point Fermin, the shoreline advanced because seacliff sediments failed and moved seaward. At Torrey Pines some of the recent movement occurred rapidly as the face of a 100 to 300-ft high seacliff dropped to the fronting beach. At Camp Pendleton and at other places along the Torrey Pines coast blocks of sedimentary material rotated and slumped seaward. At Portuguese Bend, north of Point Fermin, movement was not catastrophic, but occurred and continues to occur as a slow, non-uniform downslope creep of a huge mass of sediment. This area appears to have been moving (based on shoreline advances) since before 1934. The 3500-ft long toe of the slide at Portuguese Bend has advanced seaward almost 400 ft since 1888.

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